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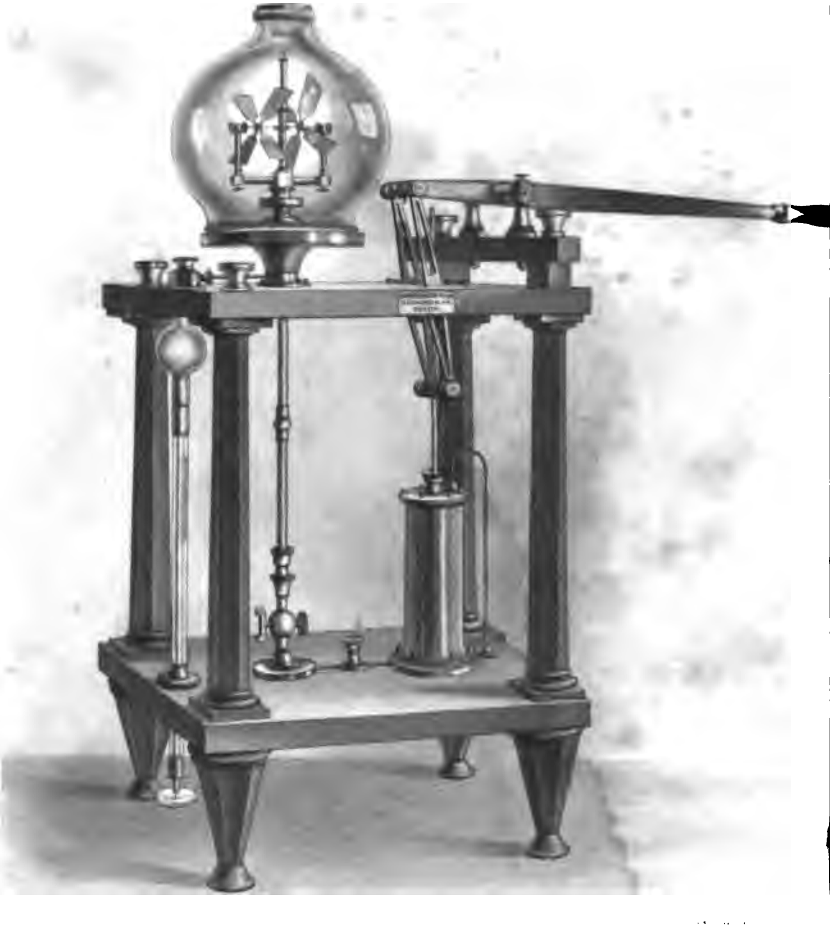

AMERICAN AIR PUMP.

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BOSTON:
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13 WINTER STREET.
1856.

THE

ELEMENTS

OF

NATURAL PHILOSOPHY;

Copiously Illustrated by Familiar Experiments,

AND CONTAINING

DESCRIPTIONS OF INSTRUMENTS, WITH DIRECTIONS FOR USING.

DESIGNED FOR THE USE OF

SCHOOLS AND ACADEMIES.

BY

A. W. SPRAGUE, A.M.

WITH TWO HUNDRED AND EIGHTY ENGRAVINGS.

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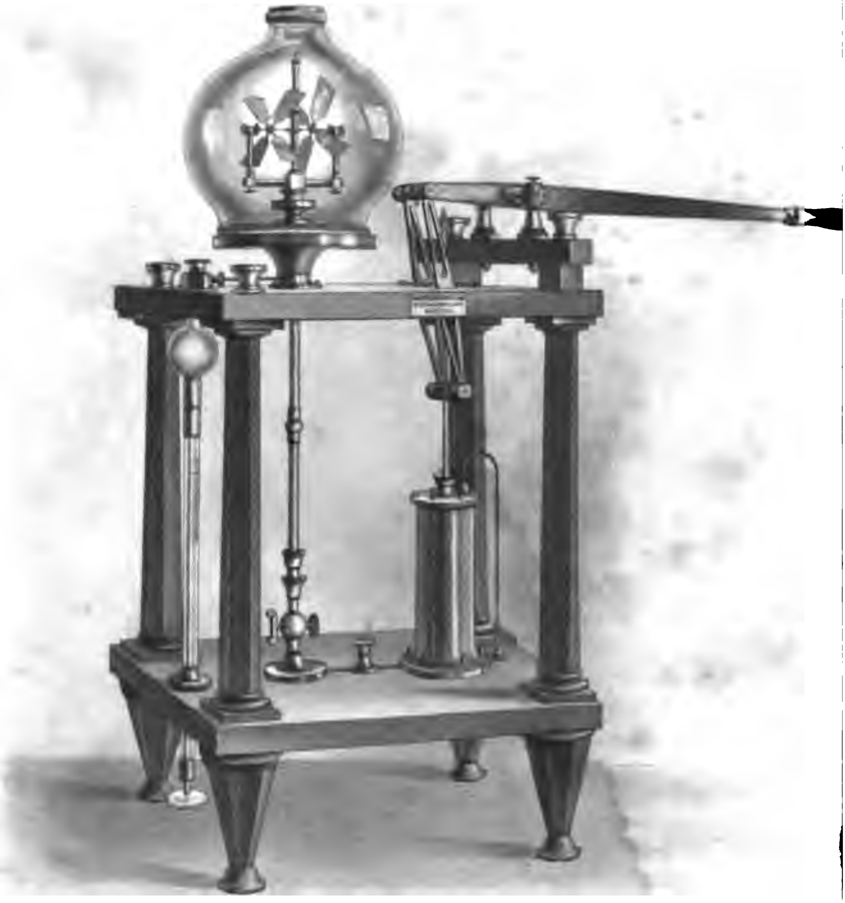

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NATURAL PHILOSOPHY.

PROPERTIES OF MATTER.

1. NATURAL PHILOSOPHY explains the laws which regulate bodies, or matter in masses. This comprises mechanics, hydrostatics, pneumatics, electricity, magnetism, and optics.

Matter possesses two *essential* properties, which are inseparable from the very idea of it; these are *extension* and *impenetrability*.

The *extension*, or magnitude of matter, is expressed by the three dimensions, length, breadth, and thickness.

Impenetrability is that property of matter whereby a body excludes from the space it occupies all other bodies. The proof of this, like extension, is too obvious to require demonstration. Thus, when the point of a knife or an awl is thrust into a piece of wood, the particles of the wood are not penetrated, but merely separated. So, when a spoon is placed in a cup filled to the brim with any liquid, the liquid flows over to make room for the spoon. Even the subtle gases, as air, are alike impenetrable; for, if we force an inverted tumbler into a basin of water, the presence of the air will exclude the water, nor can the tumbler be filled with this until the air is removed.*

---

* This is beautifully illustrated by the experiments in § 78, Pneumatics.

Define Natural Philosophy. What does it comprise? The essential properties of matter? Define extension. Impenetrability. Illustrations of impenetrability?

2. Besides extension and impenetrability, matter possesses other general properties, as divisibility, figure, porosity, inertia, and attraction.

Divisibility of Matter. — Matter is supposed to consist of ultimate *atoms*, infinitely minute and indivisible, although we are unable to determine this by any perception of the senses. As an instance of extreme divisibility, we may adduce *strychnia*, an imperceptibly small portion of which will render bitter a whole pint of water, thus dividing and diffusing itself throughout every part of the liquid. So *musk* will continue for years to send off its particles, filling the room with a most intensely-penetrating odor, and yet suffer no perceptible loss of weight. Excellent illustrations of the divisibility of matter are furnished by some metals. Thus, *gold* may be hammered so thin that three hundred and sixty thousand leaves of it, piled one upon the other, will only equal the thickness of an inch; and *platinum* may be drawn into wire so small that three millions of these wires, laid side by side, will scarcely extend over an inch in diameter.

3. The *figure* of a body is its form or shape. All bodies have a determinate form, which is implied in the idea of extension. This, however, is not confined to matter, since shadows and spectral illusions, which have no material existence, have figure.

Porosity. — The empty spaces which intervene between the particles of bodies are termed pores. These vary greatly in different substances, and determine the *density* of bodies. Thus, the pores of *lead* and *gold being smaller*, the atoms of these metals approach each other more nearly, and they are therefore said to be *more dense*.

That all bodies are porous, may be proved by the fact that

Other general properties of matter? Are the atoms of matter divisible? Illustrations of the divisibility of matter? What is meant by the figure of a body? Is figure confined to matter? What are the pores in bodies? Why are lead and gold more dense than most other bodies?

they may be compressed and made to occupy less space, which could not be done if their particles were already in contact. The porosity of many bodies may be also satisfactorily shown by the fact of their admitting within them others more subtile, without at the same time increasing their limits. Thus, into a cup filled with warm liquid a considerable quantity of sugar or salt may be thrown without causing the liquid to overflow, since the particles of the former diffuse themselves through the pores of the latter, and so occupy the spaces previously vacant. So, by means of the air-pump (§ 63), water, wood, etc., may be shown to have between their particles a large amount of space filled only with air and gases.*

4. *Inertia.* — This is a property of all material bodies, by virtue of which they are incapable of moving themselves when at rest, or of stopping themselves when in motion. The motion of a body, therefore, supposes a moving power without itself. The power which puts a body in motion, or which stops it when in motion, is termed *force.*

The numerous examples of every-day life serve to elucidate this principle of inertia in matter. A man standing upright in a boat will fall backwards when the boat is suddenly pushed from the shore, and forwards when it strikes the land again. In the former case. the whole body does not at once partake of the motion of the boat, but the feet, which rest upon it, doing this more rapidly than the upper portions, these latter fall behind, causing a fall of the body backwards; so when the motion of the boat is suddenly checked, the feet

---

* The atoms of liquids, as well as solids, are supposed to be globular. Thus, the particles of water are regarded as sustaining to each other positions similar to fine shot, and so allowing the smaller atoms of other bodies to enter and fill them.

Porosity of matter, how proved? Illustrations? Define Inertia. What does the motion of a body suppose? What is force? Illustrations of inertia? Cause of such results?

are stopped, while the head and upper parts tend to proceed, causing these to fall forwards. The same law of inertia is seen when a person jumps from a train of rail cars in motion, his feet being stopped, while the head tends to move onward, causing it to be brought violently to the ground.

5. *Attraction* is the tendency of matter, whether in atoms or masses, to be drawn together. When this exists between the molecules, or particles of a body, it is termed *molecular attraction*, or *cohesion;** when between masses of matter, *gravitation.*

6. Every body exists in one of three states, solid, fluid or gaseous, according to the force with which its particles are drawn together, or cohere.

Solid bodies are such as have the position of their particles *fixed* in relation to each other, and require a force superior to their own weight to change the form of the body; of such are wood, stones and metals.

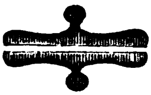
Fluids have a cohesion between their particles, which holds these within certain limits, yet allows of their gliding easily among themselves. These, unlike solid bodies, have no independent form, but take the shape of the solid surfaces within which they are confined. Water and other liquids are examples of fluids.

Gaseous bodies have a mutual *repulsion* between their particles superior to the force of cohesion, by virtue of which

---

* When the particles of two separate bodies are brought sufficiently near, they adhere and become as one body. Thus, if two perfectly polished glass plates have their surfaces cleanly wiped, and then be placed together, they will adhere, by the cohesion between their particles, so firmly as to require a very great sliding force to move them. Figure 1 shows the form of glass plates commonly used for this purpose.

Fig. 1.



Define attraction. What is molecular attraction, or cohesion? What gravitation? The three states in which bodies exist? What are solid bodies? Examples? Fluids? Examples? Gaseous bodies? Example?

they tend to separate, and occupy a volume increasing in proportion as the external pressure upon them is removed. Of gaseous bodies atmospheric air is an example.

7. *Specific Properties of Matter.*—Besides the general properties which have been described, matter contains other properties, found in a special degree in particular species of it. Such are called *specific properties.* Of these, hardness and elasticity, flexibility and brittleness, malleability, ductility and tenacity, are the most important.

Hardness is the property of matter by which the particles of a body keep their relative positions, so as to resist any force which tends to change the form of the body. This is distinct from *density*, since the most dense bodies, like lead and gold, are often comparatively soft.

Elasticity is the property by virtue of which bodies, when compressed, tend to recover their former positions again. Thus, a steel spring, an ivory ball, India rubber, and atmospheric air, are examples of elastic bodies. Elasticity exists in bodies in different degrees, and when equal to the force which presses on the body, such a body is said to be perfectly elastic. Such are the bodies just mentioned.

Flexibility and Brittleness.—When any body, as a rod of metal, readily yields or bends under a force applied to it, it is said to be *flexible.* If, however, instead of bending, the rod be readily broken, it is said to be *brittle.* Thus, a bar of steel, which has been heated, and then slowly cooled (annealed), is flexible, while the same, if suddenly cooled by plunging in cold water, is rendered brittle.

Malleability is a property which metals possess in different degrees, whereby they allow of being hammered or rolled into thin sheets or leaves. Thus iron, zinc and gold (2), are highly malleable.

What are specific properties of matter? The more important of these? Define hardness. Define elasticity. What is meant by perfect elasticity in a body? When is a body said to be flexible? And when brittle? Define malleability.

Ductility in metals enables them to be drawn out into wire. Platinum affords the most perfect example of a ductile metal (2), while iron and copper possess *both* malleability and ductility in a high degree.

Tenacity in bodies causes their particles to adhere and resist a separation. Thus, iron and copper are highly tenacious,* while tin and lead possess this quality in an inferior degree.

GRAVITATION.

8. If a stone or other body be dropped from the hand, and left free to itself, it falls until arrested in its course by some opposing obstacle, as the floor or ground.

As matter is inert (4), and incapable in itself of motion, we ascribe its fall to the earth to a mysterious force termed the force of gravity.

9. *Gravity acts on all terrestrial objects in the direction of the earth's centre.*—From whatever portion of the earth's surface a body be let fall, its tendency is invariably towards the centre of the earth.† Thus, instead of bodies falling at all points on the earth's surface, in directions *parallel* to each other, they do this at angles varying with their distances. A body let fall at Boston will make nearly a right angle with one let fall at Cape Horn; and two bodies let fall at the same time from Boston and Australia, will approach each other in nearly opposite directions.

---

* An *iron* wire one sixteenth of an inch in diameter will support a weight of five hundred and forty pounds, while one of lead, of the same diameter, will support only twenty-seven pounds. The superior tenacity of iron renders it highly serviceable in the construction of suspension bridges, and wherever great strength is requisite.

† Many phenomena of matter appear to be contradictory to this law of gravity; as the rising of balloons, the floating of clouds and various light bodies. These, however, rise, and are sustained above the earth, by reason of the force of gravity; a bulk of atmospheric air weighing more than these bodies sinks beneath, and thus forces them upwards.

Define ductility. Tenacity. Define gravitation. In what direction does gravitation act on all terrestrial objects? Illustration?

10. *Gravity acts alike on all bodies, and, where no obstacles interpose, these fall to the earth with equal velocities.* —If a flock of cotton and a ball of lead be dropped together from an elevation, the latter will fall rapidly, while the former lingers in its descent. This difference is due to no superior force of gravity exerted on the lead, but to the fact of the air offering a greater resistance to the extended surface of the cotton than to an equal mass of compact matter in the lead. If these be allowed to fall in a receiver, from which the air has been exhausted, they will both reach the earth at the same instant, as shown by experiment, § 75.

11. *The weight* of a body is the force with which it gravitates towards the earth's centre, and this force is directly as the mass of matter contained in the body.

The force of gravity diminishes in the same ratio as the square of the distance from the centre of the earth increases; hence it follows that bodies elevated above the earth weigh less than at its surface. Thus, a body, weighing one thousand pounds at the level of the ocean, loses *two* pounds when elevated four miles above this; and if carried from the earth to the distance of the moon, — two hundred and forty thousand miles, — and there acted on only by the earth, its weight would not exceed five ounces.

For this reason bodies weigh more at the poles than at the equator, from the fact of the former being nearer the earth's centre than the latter.

CENTRE OF GRAVITY.

12. There is in every body a point, about which all the particles composing the body balance each other. This point is

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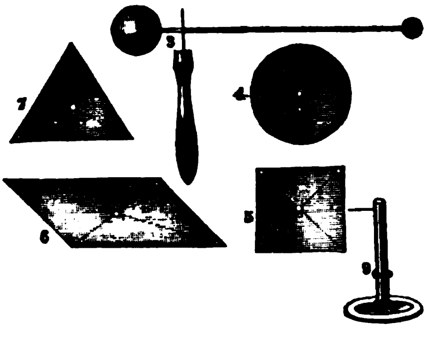
Under what circumstances will light and heavy bodies fall to the earth in equal times, and why? What is the weight of a body? How does the force of gravity diminish as we go from the earth's centre? Give an illustration. Why do bodies weigh less at the equator than at the poles? Define the centre of gravity of a body.

termed the *centre of gravity* of the body. Accordingly, if a body be supported at this point, all its parts will be in equilibrium, whichever way it be turned.

Fig. 2.



To find the Centre of Gravity. — When the particles composing the body are homogeneous (the same kind), and its form regular, the centre of gravity will be at the geometrical centre. Thus, in the triangular surface, 7 (Fig. 2), the centre of gravity may be determined by drawing lines from two of the angles, so as to bisect the opposite sides; the point where these lines intersect each other will be the centre of gravity of the surface or body. If the body be a square or parallelogram, its centre of gravity will be the point where lines, joining the opposite angular points, intercept, as shown in 5 and 6. The centre of gravity of these, as well as of homogeneous bodies, whose forms are *irregular*, may be found by suspending them freely from one of their angular points, and marking the direction of a plumb line * let fall from the point of suspension, and then suspending from another angular point, and marking again the direction of the same line; the centre of gravity will be at the point where these lines intersect. Thus, if the figures above be pierced with holes at two of their angles, and then suspended by these holes

---

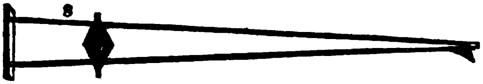
* This is shown at 2, Fig. 4, and is simply a lead weight attached to a string. The plumb is used by artisans for ascertaining when the position of bodies is perpendicular.

When the body is homogeneous and regular, how is this found? How find the centre of gravity of bodies homogeneous and irregular?

from the wire of the stand (9), or by a string, the centre of gravity will lie in the lines drawn from the wire or string perpendicular to the horizon, and at the point where these lines intersect.

13. If a body be not of uniform density, the centre of gravity will not be at the geometric centre, but at a point nearer to the denser edge. This may be illustrated by the circular body 4, Fig. 2, one side of which has been plugged with lead. In this case, if the body be placed upon the wire, with this passing through a hole at its geometric centre, the parts will not be balanced; but, in order for this, will require the wire to pass through a hole at a point nearer the lead, as seen in the figure. If such a body be balanced and made to revolve, its apparent centre of gravity will seem to ascend at each revolution. By thus plugging one side of a wooden ball, it may be made to roll up an inclined plane, since its centre of gravity may thus be made to fall before the point of support. The same singular phenomenon may be exhibited by placing a double cone at the foot of an inclined plane, formed by two angular strips, as shown in Fig. 3, when the cones will be found to roll up the plane from the angular point. This apparently contradictory motion is due to the inclination of the cones exceeding that of the inclined plane, causing the centre of gravity to fall constantly before the points of support.

Fig. 3.



Two bodies, joined by a bar or rod, may be regarded as one body. If these be of equal weights their centre of gravity will

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If the body be not of uniform density where will its centre of gravity be? Illustrate this by the figure. How may a wooden ball be made to roll up an inclined plane? Why does the double cone, seen in Fig. 8, roll up the inclined plane? Case of two bodies joined by a bar or rod, as in the figure?

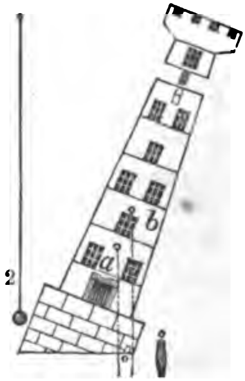
be a point midway between the two; but if of unequal weights, this will lie nearer the heavier body. This is shown by 3, Fig. 2. Here the ratios of the distances of the two bodies from the centre of gravity are inversely as the weights of the bodies.

A body in a state of unstable equilibrium will be much less liable to be upset, if it have a rapidly revolving motion about its point of support; for in this case the centre of gravity, although not directly over this point, is constantly revolving about a vertical line passing through it, and thus the tendency of the body to fall in a particular direction is prevented by a change in the point of support, so as to throw the centre of gravity in the opposite direction.

From this cause a top spins on its unstable support. Many feats of public exhibiters, as the balancing of broad plates on the point of a sword, are performed by giving these objects a revolving motion as above.

14. The equilibrium of a body is said to be *stable* whenever the perpendicular through its centre of gravity falls *within* the base; but *indifferent* when this falls just at its *edge*, and *unstable* when the perpendicular falls *without* the base. Thus, when the upper portion of the miniature tower, seen in Fig. 4, is removed, so as to bring its centre of gravity at *a*, where the perpendicular falls within the base, it will require considerable force to overturn it; but if the top be replaced, so as to bring the centre of gravity at *b*, it will have an indifferent equilibrium, and be upset by the slightest force. By any addition to its

Fig. 4.



Define three kinds of equilibrium. Illustrate these by Figure 4.

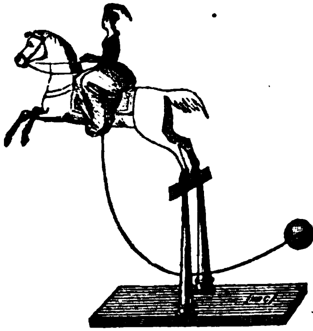
height, so as to carry the centre of gravity above *b*, the structure will be unsupported, and fall.*

The equilibrium of a body may be either stable, indifferent or unstable.

The firmness of a structure depends on the extent of the base upon which it rests, and the nearness of its centre of gravity to this base; hence, of all artifical structures, the pyramid affords the best example of stability and permanency. A regard to these led the ancient Egyptians to build the tombs designed for preserving the embalmed remains of their princes, through indefinite ages, of the pyramidal form.

Such a form of body is upset with difficulty, owing to the fact that its centre of gravity, being at a low point, must *rise through a considerable curve*, as the body turns on the edge of its base. From this cause, in turning over a flat stone or heavy marble slab, for instance, the force required at first is considerable, but gradually diminishes as the centre of gravity rises and approaches the point directly over the point of support, where the equilibrium of the body becomes indifferent.

Fig. 5.



Many amusing toys for children are constructed, illustrating the centre of gravity, where this is at or below the point of support. Thus, in Fig. 5, a horse with his rider is supported on two small wires, projecting slightly from the hind feet, by means of the lead ball

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* The leaning tower at Pisa has an elevation of three hundred and fifteen feet, and an inclination from the perpendicular of 12.4 feet; and yet stands firmly, since the perpendicular, let fall from its centre of gravity, comes within its base.

What form of structure best insures permanency? In turning over a marble slab, why does the force required becomes less and less?

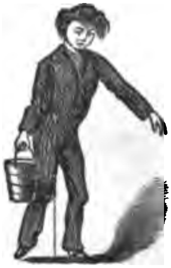
attached to the bent wire, whereby the centre of gravity is thrown below and under the point of support, causing the image to vibrate up and down from the slightest cause.

From what has been said, we see the danger of loading wagons too high, and of piling too much baggage upon the top of stage-coaches, whereby the centre of gravity will be elevated, and these thus rendered more liable to be overturned.

In the various movements of the human body, a constant effort is unconsciously made to support the centre of gravity. Since the feet afford a base so narrow, the centre of gravity would be constantly liable to fall without these, were it not for the counter motions of the arms, the head, etc., to prevent this.

Thus, the child, before it has learned the wonderful art of walking, and the intoxicated person, who disregards it, are both subject to repeated falls. The rope-dancer, on the other hand, acquires such skill in balancing the body as to walk, dance, and perform various kindred feats, on a base so narrow and unstable as a taut-rope.

Fig. 6.



A person, in carrying a weight, as a pail of water (Fig. 6), for instance, in one hand, throws out the other arm, and inclines the body, so as to bring the common centre of gravity of this and the weight within the base formed by the feet. For the same reason, in walking up hill, the body inclines forward at an angle with the hill-side, and in walking down, is thrown backwards at a similar angle.*

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* A person, in running, inclines his body so as to throw the centre of gravity a little before the point of support, and thus aid is given to his forward motion.

Why is there danger in loading wagons, etc., too high? The centre of gravity in the case of the human body? Why is a child more liable to fall than an adult? The case of rope-dancers? Why does a person in carrying a pail of water extend the other arm?

MOTION.

15. Motion is a change in the position of the body, and is opposed to rest. The power which sets a body in motion is termed *force*. Motion is of several kinds. *Relative* motion is produced when a body is moving in respect to some one body, but at rest in regard to another. Thus, a man sitting upon the deck of a vessel, is in motion in respect to the land, but at rest in regard to the several parts of the vessel. *Uniform* motion is the motion of a body moving over equal spaces in equal times. *Accelerated* motion is produced when the spaces passed over in equal times increase, and *retarded* motion when these diminish. A stone falling through the air is an instance of the former, since, acted on by the force of gravity, its rate of motion constantly increases; while the ascent of the stone, when thrown from the hand, affords an example of retarded motion.

The velocity of a moving body is measured by the space passed over in a given time. A moderate wind has a velocity of about 6.5 feet in a second; a hurricane, of one hundred and eighteen feet in a second; hence we say that the velocity of the latter is about eighteen times as great as that of the former.

Since force is required to overcome the inertia of a body and give it motion, so the same is required to bring it to a state of rest when in motion. The chief forces which act to retard or destroy the motion of a body are *friction* and *resistance of the air.*

In rising from a chair, we stoop forward, or bring the feet back, in order to cause the centre of gravity to fall within the point of support. Thus the movements of the body, in its various positions, all regard the law of equilibrium of solids.

Define motion. Force. What is relative motion? Uniform motion? Accelerated motion? Retarded motion? Illustrations of accelerated and retarded motion? How is the velocity of a moving body measured? Illustration? What are the forces which act on bodies to bring them to a state of rest?

16. *Momentum.* —This is the force which a moving body exerts, and is as the mass of the body multiplied into its velocity. For equal masses of matter the momentums are as the velocities; and for equal velocities, as the masses. Thus, a body weighing ten pounds, and moving with a velocity of five hundred feet in a second, will have a momentum of (10×500) five thousand, while a second body, also weighing ten pounds, and moving with a velocity of two hundred and fifty feet in a second, will have a momentum of only (10×250) twenty-five hundred. In this case the momentum of the former is double that of the latter.

The velocity of a body may be very small, and yet have a very great momentum. This is illustrated in the case of icebergs or large timber-rafts, moving with a motion almost imperceptible, and yet producing effects the most terrific when meeting with other large masses.

17. *Gravity gives to falling bodies a constantly increasing or accelerated motion.*

If a person leap from a chair to the ground, he suffers no injury, while, if he do the same from a church belfry, he will most probably strike the ground with a force sufficient to destroy life. Now, since this force depends on the velocity with which the body moves at the moment when it touches the earth, it follows that the velocity of the body is increased with the height.

Laws of Falling Bodies. — Bodies in falling towards the earth observe certain laws in regard to the rates of their velocity. Thus, if a body fall sixteen feet in the first second of its descent, it will fall three times that in the next second, five times in the third second, seven times in the fourth second, and so on; the spaces through which it moves in each successive

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Define momentum. Illustrate this. How does gravity affect the motion of falling bodies? Example? State the law in regard to the velocity of falling bodies.

second being as the odd numbers 1, 3, 5, 7, etc. The total distance fallen through from the place of rest will be as the *squares of the times*. Thus, if a body dropped from an elevation fall 16 feet in the first second, the distance reached at the end of the next second will be (2^2) four times that, or 64 feet; at the end of the third second, (3^2) nine times, or 144 feet, and so on. Thus, to ascertain the entire distance a body will fall in a given time, we have only to multiply the space through which it falls in the first second by the square of the number of seconds it is falling.

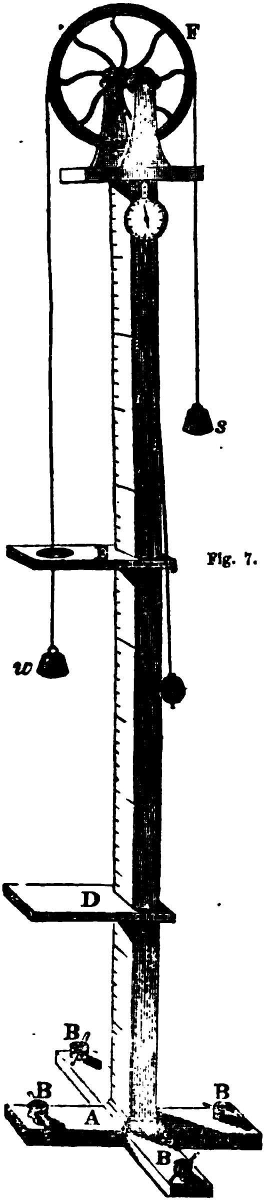

Fig. 7.

Atwood's Machine, Fig. 7, is an ingenious yet simple device (for ascertaining the rate of increase in the velocity of falling bodies.) This was contrived for the purpose of obviating the difficulties attending attempts to determine the velocities of these by actual measurements, and consists of a grooved wheel, *F*, revolving on delicate bearings placed upon the top of a tall, graduated, vertical post. Over this wheel passes a fine cord, to the ends of which are attached the weights *w*, *s*, precisely equal. To the front of this post is affixed a clock with its pendu-

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How will be the total distance fallen through by a body? Explain this. How may we ascertain the entire distance a body has fallen in a given time? What is the use of Atwood's Machine? Describe the parts of this.

lum vibrating seconds. D and E are planes movable up and down on the post; the latter having a circular opening just sufficient to allow the weight *w* to fall freely through it, while it intercepts and takes off a small oblong weight * placed on this.

Experiment. — Bring the post into a vertical position by means of the screws B B; draw *w* to the top of the graduation, place upon it the small weight, and let them descend; the velocity of *w* will be comparatively slow yet constantly increasing until it passes through E, when the small weight will be taken off, and *w* will continue its descent to D, by reason of the gravitating force of the small weight acting down to the point E. Now, since gravity acts alike on all falling bodies, small and great, causing them to fall alike when the air offers no resistance, and since the increase of the velocity of *w* (during the successive intervals of time as indicated by the pendulum) is in the same proportion as that of a body falling freely during the same time, it follows that from the rate of increase in the velocity of *w*, as may be clearly indicated by this machine, the increasing velocity of bodies in general may be determined. The spaces passed over by the descending weight *w*, in successive seconds, are found to be as the squares of the times of falling. To determine, therefore, the distance a body has fallen in a given time, we have only to multiply the space fallen through in the first second by the square of the number of seconds.

Owing to this accelerated motion of falling bodies, a bullet or a cannon-ball dropped from an elevation sufficiently great, may acquire a velocity and force far greater than if fired from a rifle or cannon.

18. *Motion of Projectiles.* — When a body is thrown in a direction oblique to the perpendicular, it is acted on by two forces,

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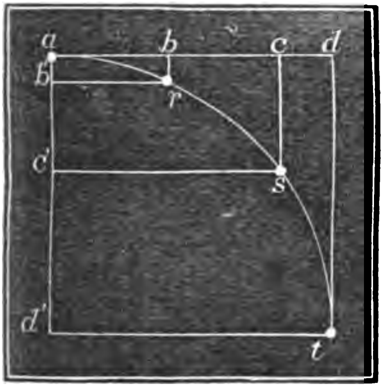
* This small weight is not shown in the figure.

How does the slow descent of the weight *w* indicate the rate of velocity of falling bodies in general? What is said of a bullet or cannon-ball let fall from a great elevation?

the projectile force, which tends to impel it forward in a straight line, and the force of gravity, which acts to bring it to the earth. Instead, therefore, of following the direction of either, the body describes a curve between the two forces. This may be illustrated by Fig. 8. Let any body, as a cannon-ball, be projected horizontally from an eminence at *a*. Suppose *b* the point to which the projectile force alone would carry the body in one second, and *b′* the point which it would have reached by gravity alone in the same time; then, instead of following the direction of either of these forces, it will move in a curve, *a*, *r*, between them. So, in the next second, instead of passing to the points *c* or *c′*, under these combined forces it will move to *s*; in the third second to *t*, and so on, describing in its descent that form of curve known as the *parabola*.

Fig. 8.



The law of motion of projectiles is especially regarded in the art of *gunnery*. By knowing the force of the powder which drives the ball, the engineer is enabled so to elevate his cannon or mortar as to cause the ball or shell to fall on a particular spot in the distance.

19. *Central motion* is the motion produced by the revolution of a body about a fixed point; as when a ball attached to a string is made to revolve about the finger. Owing to the *inertia* of bodies causing them to persevere in straight lines, these, when revolving in a circle, tend constantly to recede from the centre

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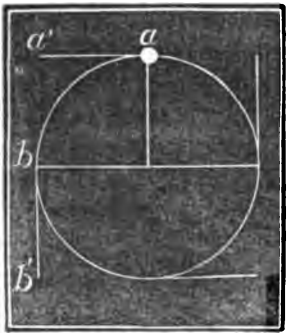
What forces act on a body thrown oblique to the perpendicular? What direction will such a body take? Explain Fig. 8. Where is the law of motion of projectiles especially regarded? Define central motion.

Fig. 9.



of motion, and fly off in a tangent to the circle. Thus, in Fig. 9, the body *a*, at the points *a*, *b*, tends to move in the direction of the tangents *a a'*, *b b'*, and so at every other point in the circle.

The force which holds a body and confines it in its circular path, is termed the *centripetal* force;* that which causes it to fly off, the *centrifugal.*†

While these forces are balanced the body moves in a circular course,‡ but when either preponderates it moves in the direction of the preponderating force. This is seen in the revolution of an apple attached to a string fastened to the finger. If the motion be too rapid, so as to break the string (centripetal force), the apple will fly off in a tangent; but if too slow, it will fall in towards the finger. Owing to this centripetal force, a pail of water or a tumbler of water fixed in a sling may be made to revolve without the liquid flowing out. The same force causes water to fly off from a grindstone, or mud from a rapidly revolving carriage-wheel.

A magnificent illustration of the balancing of these two forces, so as to cause a harmonious revolution, is furnished in the motions of the heavenly bodies.

20. *The centrifugal force increases with the distance from the centre of motion.*—Thus, in the revolution of a body about

[*] Centre, and *peto* to seek. [†] Centre, and *fugio* to fly off.

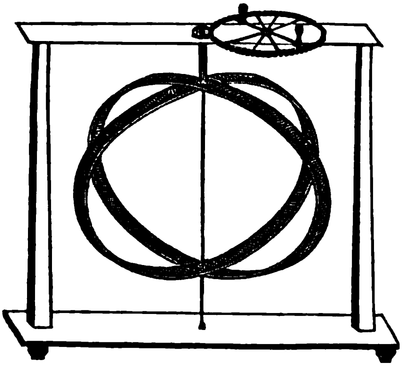
[‡] The danger of upsetting a carriage in turning rapidly round a corner is due to the fact that the centrifugal force causes the centre of gravity to be thrown without the wheels or point of support.

Explain the causes of the circular motion of the body seen in the figure. What is centripetal force? Centrifugal? How does a body move when these forces balance? Illustrations? What bodies illustrate the balancing of these forces? State the proposition in regard to the centrifugal force.

a fixed axis, as the earth for instance, those parts more remote are acted on by the centrifugal force much more strongly than those nearer this axis. To this cause is commonly ascribed the present form of the earth, bulging out at the equator and flattened at the poles; this having commenced its revolution at an early epoch, probably while it was in a plastic state.

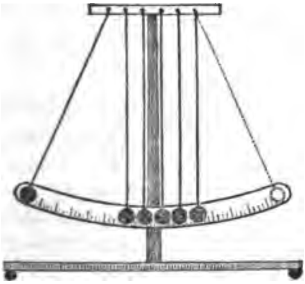
This change in the form of revolving bodies may be illustrated by Fig. 10. This consists of two elastic hoops fastened at the upper side on a vertical shaft, while the lower is free to move. Rapid motion is given to this by geared wheels at the top of the frame, when the hoops will be found to bulge out at the equator, but contract at their poles, as already stated.

Fig. 10.



When a body in motion strikes against another body, the former acts upon the latter, and in turn is acted on by it. The effect of the moving body is termed *action*, and of the body it strikes, *reaction*. Action and reaction are equal and in opposite directions. This may be proved by the apparatus shown in Fig. 11, where six ivory balls are suspended by fine cords so as to hang parallel before a graduated arc. If, now, one of the balls be drawn back to a certain point on the arc, and then let fall, it will act

Fig. 11.

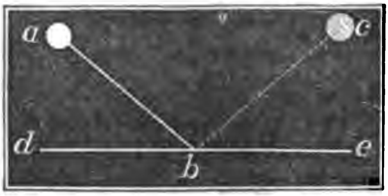


Cause of the present form of the earth? How illustrated by the figure? Define action and reaction. What law do these observe? Explain Fig. 10

on the second of the series, this second ball will act on the third, the third on the fourth, and so on; each imparting force to the next, until the last ball, having no other to which to impart its force, flies off to nearly the same distance as the first was removed; thus showing action and reaction to be equal where the bodies are perfectly elastic.

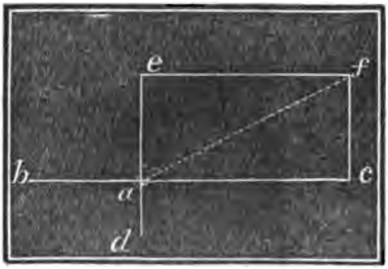
21. *Reflected Motion.* — When any elastic body, as an ivory ball, is thrown against a hard smooth surface, it rebounds from such surface, and the motion it receives is called *reflected motion.* In such a case, the angle which the body makes with the surface when approaching it is called the *angle of incidence,* and that which it makes with this when leaving it, the *angle of reflection;* these angles are equal.

Fig. 12.



Thus, let an elastic ball be thrown from the point *a*, Fig. 12, striking the hard smooth surface *d*, *e*, at *b*, when it will be reflected in the direction *b*, *c*. In this case, *a*, *b*, *d*, is the incident, and *c*, *b*, *e*, the reflecting angle, and upon measuring these angles they will be found equal.

Fig. 13.



22. *Resultant Motion.* — When a body is struck at the same instant by two forces, whether equal or unequal, instead of following the direction of either it will move in a line between these forces; this line or direction will be the diagonal of a parallelogram whose adjacent sides represent

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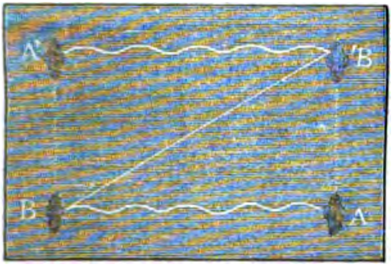
What is reflected motion? How are the angles of incidence and reflection? Explain Fig. 12. What is resultant motion? Illustrate this by the figure.

the forces, and will itself represent the resultant of these forces. Let *a*, Fig. 13, be a billiard ball, for instance, struck by two unequal forces in the directions *b*, *c*, and *d*, *e*; the ball, instead of following the direction of either, will move in the diagonal *a*, *f*, between the forces.*

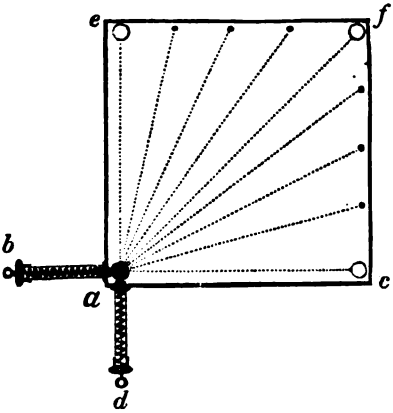
Fig. 14.



The scenes of daily life afford numerous examples of resultant motion. A vessel in attempting to cross a river presents a good illustration. Thus, in Fig. 14, let B be a steamboat attempting to cross the stream in a direct line to A′. Suppose

* Fig. 15 is a convenient apparatus for showing the resultant of two forces acting simultaneously on a body. Two springs, *b* and *d*, are placed at one corner of a rectangular table, so as to act equally on a ball, *a*, if desired. If *b* or *d* be worked separately, it will impel the ball in a straight line in the direction of the forces to *c* or *e*; if both these act equally, and strike *a* at the same instant, it will move in the diagonal *a*, *f*, between the forces. If the springs be drawn out so as to act unequally on *a*, they may be so regulated as to drive it in any direction between *c*, *f*, and *e*, *f*.

Fig. 15.



Many wonderful feats of circus-riders are examples of resultant motion; such as jumping from the back of a horse in rapid motion, over a rope or through a hoop, so as to alight again on the back of the animal. The spring of the body in such instances gives to it an upward motion, while it retains its forward motion in common with the horse.

How is resultant motion illustrated in case of a steamboat attempting to cross a river?

the force of the steam sufficient to drive it to A′ in ten minutes, while the force of the current is sufficient to carry it in the same time to A. If, now, steam and current act simultaneously, instead of passing to either A or A′, the steamboat will move in a diagonal between the two forces, and arrive at the expiration of the time at B′.

In throwing a package from a train of cars, or an apple from the deck of a steamer, these bodies partake of the motion of the cars or steamer, so that, instead of striking at the point intended, they are carried along some distance beyond. Thus, in firing from a sailing-vessel at an object at rest, due allowance should be made for the motion of the vessel, and aim taken behind the object.

In jumping upwards from the floor of a rail-car in rapid motion, a person unacquainted with the laws of resultant motion might very naturally suppose the car would pass from under him so as to cause his feet to strike again at a point behind that from which he jumped, instead of returning to this same point, as is found to be the fact. So, in dropping a ball from the mast-head of a vessel sailing rapidly, an ignorant person might suppose the ball to strike astern, instead of at a point on the deck directly beneath, as the trial will prove.

PRACTICAL PROBLEMS ON THE FOREGOING PRINCIPLES.

1. What distance would a pigeon, flying uniformly at the rate of 68 miles per hour, pass over in 12½ hours?

2. A train of rail-cars which, with the locomotive, weighed 180 tons (403,200 lbs.), and moving at the rate of 18 miles per hour,

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In throwing a package from a rail-car, or the deck of a steamer, will it strike the point at which it is aimed? In firing from a sailing vessel at an object at rest, where should aim be taken? In jumping upwards from a rail-car, when moving rapidly, why does not the car pass from under the person?

was met by a second train weighing 165 tons (369,600 lbs.), and moving at the rate of 22 miles per hour; what was the force or momentum of their collision? (§ 16.)

3. A grindstone in an axe factory burst asunder from its too rapid revolution, and a portion weighing 428 lbs. was hurled against the wall with a velocity of 30 feet per second; with what force did it strike this?

4. A stone, let fall from a precipice above a body of water, was seen to strike this in five seconds; what was the elevation above the water? (§ 17.)

[Suppose 16 feet to be the distance fallen through in the first second; then $16 \times 5^2 = 400$. *Ans.*]

5. A ball shot perpendicularly upwards from a rifle returned in 12 seconds; how high did it ascend?

[$6^2 \times 16 = 576$. *Ans.*]

6. If a body be hurled downwards with a velocity of 22 feet in the first second, how far will it fall in 9 seconds?

[Since the total distance fallen through by a body will be as the square of the time of its fall (§ 17), the answer in this example will be found by multiplying 9^2 (81) by the distance fallen through in the first second.]

7. A stone, thrown directly at an object from a rail-car moving at the rate of 3,520 feet per minute, was 4 seconds in the air; at what distance beyond the object did it strike?

8. A cannon-ball fired from a steam frigate was seen to strike a fort three miles distant in $1\frac{1}{2}$ seconds; supposing the frigate to be moving at the rate of 15 miles per hour, how far behind the fort would it be necessary to aim in order that the ball might strike it?

9. Two steamboats moving in opposite directions pass each other, one going at the rate of 11 and the other 14 miles per hour; suppose an apple be thrown from the deck of one boat at a person in the bow of the other boat, how far astern will it strike the water in $3\frac{1}{2}$ seconds?

10. In carrying a heavy package along a narrow pass upon the verge of a promontory on the island of Atoi, several years since, a man was seen to lose his balance and fall, and in $4\frac{1}{2}$ seconds after to strike the water beneath; how high was the promontory?

THE MECHANICAL POWERS.

23. MACHINES are instruments employed for aiding muscular and other forces in overcoming physical resistances. These, however complicated, are made up from a few simple machines, termed the *mechanical powers.* It must not be supposed that we generate or increase force by means of these simple machines; we merely apply this in a convenient and economic manner. Thus, if a man could raise to a certain height two hundred pounds in one minute, with the utmost exertion of his strength, no power could enable him to raise two thousand pounds in the same time. If left to elevate this mass by his own unaided strength, he would be obliged to divide it into ten equal portions, and raise each separately; whereas, by making use of one of the simple machines, he will be enabled to raise the whole mass at once, requiring, however, for the performance of the task, ten times as many minutes as for raising the two hundred pounds.* Thus, in the use of these simple machines, time is exchanged for power. And the same is true of all the numerous varieties of mechanical contrivances for facilitating labor.

24. The mechanical powers, or simple machines, are commonly regarded as six in number: the Lever, the Wheel and Axle, the Pulley, the Inclined Plane, the Wedge, and the Screw.

The Lever.—This is any bar, turning on a fixed point or prop. This prop is termed the *fulcrum,* and the parts of the bar extending on each side of this the *arms* of the lever.

Levers are of three kinds. First, where the fulcrum is between the power and the weight. *Second,* where the weight is between the power and fulcrum. *Third*, where the power is between the fulcrum and weight.

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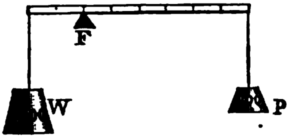
* Bird.

What are machines? From what are these made up? Do we generate force by the use of machines? Illustrate this. The number and names of the mechanical powers? Define the lever. The kinds of levers?

Fig. 16.



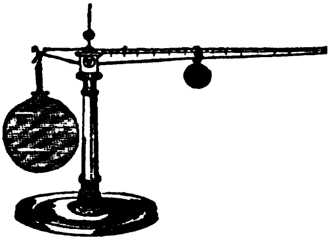
The first kind of lever is shown in Fig. 16, where P represents the power, W the weight or resistance, and F the fulcrum.

The crowbar employed for prying up rocks, pump-handles, steelyards, scissors and pincers, are illustrations of this kind of lever.

The power and weight are always in equilibrium when they are to each other in the inverse ratio of the arms of the lever to which they are attached. Consequently, in Fig. 16, in order that the power, P, and the weight, W, exactly balance each other, the products arising from multiplying each by its distance from the fulcrum must be equal. Thus, if we suppose W to be a weight of three hundred pounds placed two feet from F, and P a power of one hundred pounds placed six feet from F, then will W and P be in equilibrium, for $(300 \times 2) = (100 \times 6)$. Thus, when the weights and lengths of the two arms of the lever are given, the power to balance the weight may be found by dividing the product of the weight into its distance from the fulcrum by the distance of the power from the same.

The *balance* and *steelyard* are examples of the application of the first kind of lever. The latter, as seen in Fig. 17, has the length of its arms unequal. The body to be weighed is suspended from a hook near the fulcrum, and counterpoised by a small weight, moveable upon the other, or long arm; the weights which this small weight will bal-

Fig. 17.

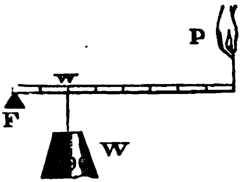


Describe a lever of the first kind. When are the power and weight in equilibrium? Illustrate this by the figure. What familiar examples of the first kind of lever?

ance at different points, being indicated by figures marked on this long arm. By this inequality in the two arms of the steelyard the weights of heavy bodies may be indicated.

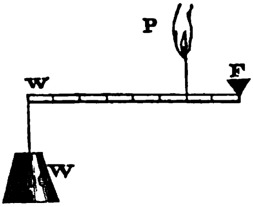
25. Fig. 18 represents a *lever of the second kind.* Here the fulcrum, F, is at one end of the lever, the power, P, acting at P at the other, while the weight, W, is between these. The power and weight will be in equilibrium in this as in the previous case, when (W × w F) = (P × P F). An oar employed in rowing a boat is an example of this kind of lever; in this instance the water is the fulcrum, the boat the weight or resistance, and the hands the power. Wheelbarrows, doors, hay-cutters, and nut-crackers, are also examples of the same.

Fig. 18.



26. *The third kind of lever* may be illustrated by Fig. 19, where W, the weight attached at w, is at one end; F the fulcrum, at the other, and P the power applied at P between these, when the power and weight balance (w F × W) = (P F × P).

Fig. 19



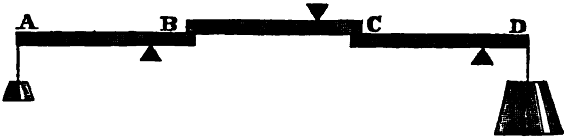
As will readily be seen, the power of this form of the lever must always exceed the weight to be raised. Hence, owing to its mechanical disadvantages, this lever is never used, except where *velocity* is required more than power. A pair of tongs, the treadle of a lathe, and the raising of a ladder by lifting upwards when one of its ends is fixed, afford illustrations of levers of the third kind.

Explain the second kind of lever from the figure. Examples of this kind of lever? Explain from the figure the third kind of lever. In this kind of lever, how must the power be in reference to the weight?

The limbs of animals afford the most striking examples of this form of lever. Here the tendons, which connect with the muscles which move the limbs, are attached, as in the fore-arm, to the bone near the joint on which the limb turns. Thus, a short yet powerful muscular contraction at the hips and shoulders gives the sweep to the legs and arms from which the body derives so much activity.

27. *The Compound Lever* is a combination of simple levers acting one upon the other, whereby the power of a small force in overcoming a large resistance is greatly multiplied. Such an arrangement is shown in Fig. 20. Here A B represents a lever of the first kind, which acts on a second lever, B C, and this again on C D, a third lever; thus enabling a small force at A to overcome a large resistance at D. To ascertain the weight or force which a given weight or power at A will balance at D, we have only to multiply together the numbers expressing the lengths of the arms upon the left of the three fulcrums, and this product into the power at A, and then divide the result by the product arising from the continued multiplication of the numbers denoting the lengths of the arms on the right. If, for instance, the arms of the levers upon the left, be 6, 6, 6, and those on the right 2, 2, 2, and the power at A one pound, then if $(6 \times 6 \times 6 \times 1) \div (2 \times 2 \times 2) = 27$ pounds, the weight which one pound at A will balance at D. *

Fig. 20.



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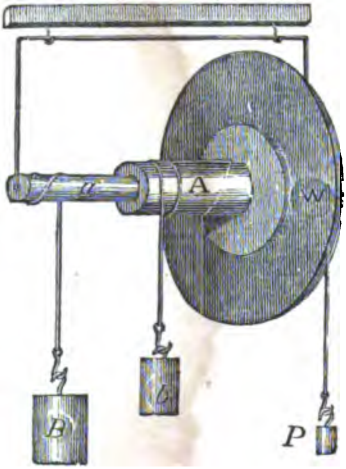
* In the various calculations in mechanics, the levers are regarded only as imaginary lines, and no account is taken of friction, etc.; these causes modify somewhat the practical results.

Examples of the third kind of lever? What is a compound lever? Explain this from the figure.

The knee lever, hay-scales, etc., are instances of the application of the compound lever.

28. *The Wheel and Axle.*—In raising a weight to any considerable height, by means of the common form of lever, it is necessary for this to act through a succession of interrupted movements. To avoid this, and enable the power to act by a continuous motion, the wheel and axle are employed. This, then, may be regarded as a modified form of the lever.

Fig. 21.



This machine is shown by Fig. 21, where W represents the wheel, and A *a*, the axle. The power, P, acts by means of a rope passing in a groove upon the circumference of the wheel. This wheel is oftentimes supplied by levers fixed in A, to the ends of which the power is applied. The resistance or weight, B, to be raised, is attached to a rope which winds around the smaller cylinder, *a*. Here the radius of the larger wheel corresponds to the long arm, and that of the smaller wheel or axle, to the short arm of the lever. Accordingly equilibrium is obtained when the power applied is to the weight to be raised, or resistance to be overcome, as the radius of the axle is to that of the wheel. If R be the radius of the wheel, and r that of the axle, then the power, P, and weight, B, will be in equilibrium, when $P \times R = B \times r$. So also the weights b, and B, will be in equilibrium when the

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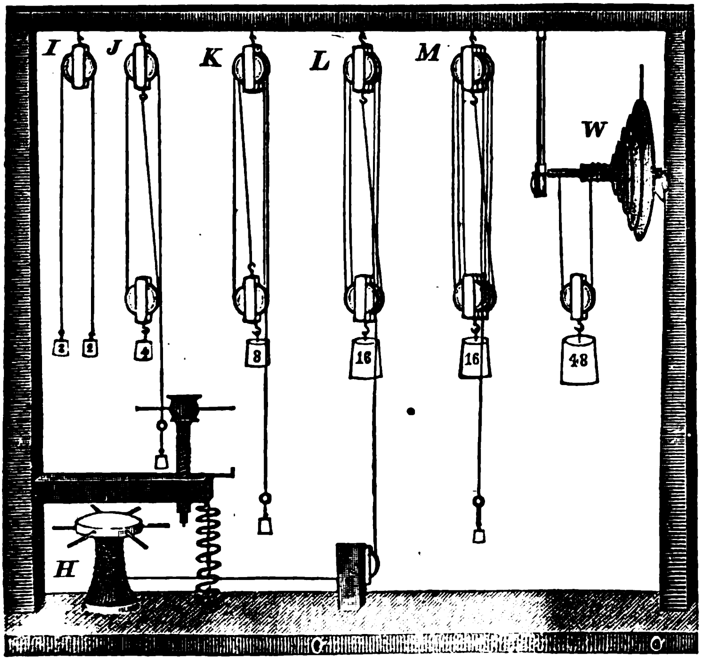
Instances of the application of the compound lever? In what cases is the wheel and axle used, and how may it be regarded? Explain its operations by the figure. When will the power and weight be an equilibrium? What is the windlass?

product of *b*, into the radius of the larger axle, A, is equal to that of B, into the radius of the smaller axle, *a*. The *windlass*, seen at W, Fig. 22, is a form of the wheel and axle, in which the power is applied to levers fixed in the circumference of the wheel. In this case, the rope attached to the weight, when this is raised, winds off from a smaller upon a larger axle. In this manner a great weight may be raised by a small power, and with a simple machine. Such a form is usually termed the *differential* wheel and axle.

Fig. 22.



The Capstan is a form of the wheel and axle usually employed on shipboard for raising anchors, or upon wharves for

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Describe the capstan.

moving vessels and other ponderous bodies. This is usually placed in a vertical position, and has levers fixed in its larger circumference, or temporarily inserted in holes provided for these. The form of the capstan, with the cable winding upon this, is shown at H, Fig. 22.

Where great power is required, or where it is desired to transmit the power in another direction, a combination of wheels, connected by cords or bands, or by teeth upon their circumferences, is employed. Such an arrangement acts on the principle of the compound lever, already described.

29. *The Pulley*, strictly speaking, consists of a rope or cord sliding over a *fixed* point or cylinder, and acts upon the principle of the lever. As commonly understood, however, this consists of a rope moving over a grooved wheel, which turns on pinions, the wheel being introduced to prevent friction. The use of the pulley gives no increase of power, but simply affords a convenient mode of applying power.

Pulleys are divided into *fixed* and *movable*. At I, Fig. 22, is seen the simple form of the *fixed* wheel-pulley. Here no power is gained, but merely a convenient application of power in the moving of bodies is afforded. Thus, if a weight is to be raised from the ground up to the point I, it may be done with far less difficulty by a person pulling *down* upon the rope passing over a wheel, than if the same person apply his power at I in pulling *up* on this rope. So, in raising bales of goods and heavy merchandise to the upper stories of warehouses, or from the holds of vessels, the pulley affords a highly convenient means of changing the direction of the power, and so facilitating the expenditure of labor.

Of what does the pulley, strictly speaking, consist? Of what does it consist as commonly understood? What advantage does the use of the pulley afford? How are pulleys divided? Explain the first or simple form of the pulley. Where is this form employed? Is there any power gained by it, and, if not, what are the advantages of its use?

At J, Fig. 22, is shown a *fixed* and a *movable* pulley. Here the weight attached to the lower blocks is supported by the two parts of the cord which passes around the wheel of this block; and consequently the power upon the free end of the cord requisite to balance this weight of 4, will be 2. Hence, in this, as in the combinations at K and M, the power will be to the weight it will balance as 1 to the number of cords supporting the lower block. Thus, if 8 represent the weight at K, and the number of cords which support this weight be three, then, since each cord will sustain one third of this, the power at the free end of the cord requisite to maintain the equilibrium will be one third the weight. So at M, where the weight is supported by six cords, the power to equilibriate with this will be one sixth the weight.

From its portable form, cheapness of construction, and the facility with which it may be applied in almost every situation, the pulley is one of the most useful of the simple machines. The mechanical advantage, however, which it appears in theory to possess, is considerably diminished in practice, owing to the stiffness of the cordage and the friction of the wheels and blocks. From these causes it is computed that in most cases two thirds of the power is lost. The pulley is much used in building, when weights are to be elevated to great heights; but its most extensive application is found in the rigging of ships, where almost every motion is accomplished by its means.

30. *The Inclined Plane.*—If a person, in attempting to raise a heavy body, as a cask for instance, find its weight unequal to his strength, he may accomplish his object by causing the body to be supported in part by an inclined surface, and exerting his force in a direction parallel to this inclined surface. Thus, in

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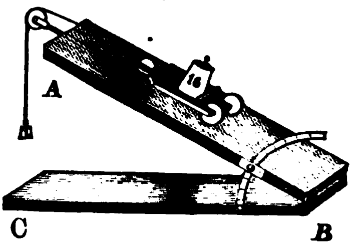
Explain the fixed and movable pulley. In these combinations of pulleys how is the power to the weight? What is said further of the use of the pulley? Where is it much used? Illustrate the use of the inclined plane for facilitating the raising of a heavy body.

loading a barrel into a wagon, a plank is laid with its lower end resting upon the ground, and the barrel rolled up this by a force much less than would be required to raise it perpendicularly to the same elevation. The plank in this case forms an *inclined plane.*

Fig. 23 presents a view of this simple machine, by which the weight upon the truck is raised to a given height by a force comparatively small. Here it will be readily seen that the inclined surface sustains the greater portion of the weight, while the power acting in the direction of the plane sustains the remainder.

Fig. 23.



In Fig. 23, A B is the length of the inclined plane, B C its base, and the distance between A C its height. If the weight placed upon the inclined plane consist of as many pounds as there are inches in the length of the plane, the pressure on the plane will be equal to the number of inches in the base, and the tendency to move down the plane will be balanced by as many pounds as there are inches in the height; so that the force requisite to draw the body up an inclined plane will be to the weight as the height compared with the length.

In this as in other simple machines a gain in power is always attended by a corresponding loss of time. This is seen in roads, which when not level may be regarded as inclined planes. If a road be made to pass directly up the side of a steep hill, a far greater power, but a much shorter time, will be required to draw a loaded wagon to its summit, than if the road wound around the sides of the hill at a less angle of inclination.

Describe this simple machine from the figure. In raising a body up an inclined plane, how will the power be to the weight? In the use of the inclined plane, with what is the gain in power attended? Give an illustration.

31. *The Wedge.*—If, instead of moving a load on an inclined plane, the plane itself be moved beneath the load, it then becomes a wedge. Thus, if a heavy beam be secured in a vertical position, and be free to move upwards and downwards, but not laterally, and an inclined plane, on which its end rests, be forced under it, the beam will rise by the motion of the plane merely. Such an inclined plane becomes a wedge.

This simple machine is formed by two inclined planes laid base to base, as seen in Fig. 24.

Fig. 24.

The power requisite to force the wedge beneath a resisting body will increase with the increase of the angle of inclination of its sides.

The wedge is used in the arts and manufactures where immense force is required to move a body through a very small space. It is, therefore, used in raising vessels in docks, when about to be launched, by driving under their keels; and also in oil-mills, for forcing out the oil from seeds, which are placed in bags between the plates of the press. It is chiefly used, however, in cleaving logs and masses of stone.

Cutting and piercing instruments, as knives, shears, awls, etc., act on the principle of the wedge. The sides of these, where the power acts continuously, should form with each other a smaller angle, or be sharper, than where the wedge is driven by percussion, as in the splitting of timber, rocks, etc.

32. *The Screw.*—When a road, instead of leading up a hill directly, winds round to its summit so as to lengthen the inclined plane, and thus aid the moving force, this inclined plane becomes a screw. In this manner a pair of stairs, winding around the sides of a cylindrical tower, either within or without, affords an instance of an inclined plane so modified as to become

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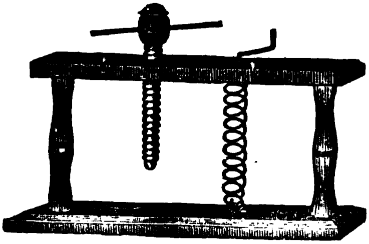
Illustrate the principles on which the wedge acts. How is the wedge formed? What relation has the moving power of this to the inclination of its sides? Where is the wedge used? On what principle do cutting and piercing instruments act? Give illustrations of the screw.

a screw.* Thus it will be seen that the screw is but another form of the inclined plane. This may be best illustrated by winding about a small cylinder a strip of paper, cut at an angle so as to represent such a plane, and then tracing the course of its edge. This will be found to mark the direction of the thread of a screw, thus showing this to be but a winding inclined plane.

The form of the screw and course of the thread are shown by Fig. 25.

Fig. 25.



The screw is not applied directly to the resistance to be overcome, as in the case of the inclined plane or wedge, but acts upon this through the screw-box, or *nut*. This is a cylindrical cavity, having a spiral groove cut around its interior surface to correspond with the elevations of the screw, and in which these move. This groove of the nut is termed the *interior* screw, and the elevations of the cylinder moving in this, the *external* screw.

33. Power is commonly applied to the screw by means of a lever, either attached to the nut or to the head of the screw, as seen in Fig. 25. By varying the length of this, the power may be indefinitely increased at the point of resistance.

Where the power is applied to the end of a lever attached to the screw, the comparative velocities of this and the weight or

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[*] Olmsted.

Of what machine is the screw a modified form? How illustrated in case of a cylinder and strip of paper? Through what does the screw act upon the resistance? Describe the screw-box or nut. How is power commonly applied to the screw? Where the lever is applied to the screw, state the relation between the velocities of the power and resistance.

resistance will be as the circumference of the circle described by the power to the distance between the contiguous threads of the screw. The same ratio of motion will also constitute the ratio between the power and weight when these are in equilibrium; and hence, the longer the lever, and the nearer the spirals of the thread, the greater will be the mechanical force exerted by the screw.

The screw is generally used where great pressure is to be exercised through small spaces; hence its agency in most presses. Thus, in the coining of money, where a prodigious force is required to impress the die upon the metal, the screw is employed. So, also, in compressing cotton, hay, and other light and bulky bodies, in order that they may occupy the least possible space in transportation, this same machine usually acts a part.

MACHINERY.

34. All machines, however complicated, are only applications of some one or more of the simple mechanical powers just described. Thus, if we examine carefully the various parts of a complex machine, as a steam-engine, or a loom for weaving, we shall find these formed of simple levers, wheels, screws, etc., combined in various ways to make up the entire whole.

The use of machines is not to create force, but merely to afford a means of applying this to advantage. This is obvious from the fact that these are mere inert matter, and incapable of doing more than to transmit the force or power imparted to them. In the use of the windlass for raising water from a well, or coal from a mine, the application of the power to the crank may be made with far greater convenience than to the rope winding upon the axle, and to which the weight is attached. So, in the rigging of ships, or the raising of materials for building, a pulley is interposed between the power and the weight,

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Where is the screw generally used? Of what are all machines composed? The use of machines? Give an illustration.

not to increase the force of the former, but merely to give it a convenient and efficient direction. Whatever form of machine, therefore, be introduced between the power and resistance, it can add no mechanical energy to the former, but will, in fact, owing to friction and other causes of resistance, intercept a portion of the action of this power while transmitting it from the point of application to its working point.

35. *Machines serve to give intensity, direction, and velocity to the power.* — To raise a weight of one thousand pounds by an unaided muscular force of two hundred pounds, would be impossible; but, by interposing a lever, or a screw and lever, *intensity* may be given to this force, whereby the weight shall be readily raised.

In a windmill the power is the wind, which acts with a continuous rectilinear force on the arms, while the stones, which are the resistance, revolve with a circular motion around a vertical axis. Here, as will be readily understood, the change in the *direction* of the force transmitted from the power to the resistance is effected by the use of a series of wheels. So, in a saw-mill, the force of the water communicates a *rotary* motion to the wheel, and this motion, by means of a crank, is converted into a *reciprocating* motion, as seen in the ascent and descent of the saw.

Again, if a power having a certain *velocity* be required to impart a greater or less velocity to the resistance, then a machine must be interposed which will regulate this velocity in the required proportion. This is seen in the pulleys of a turning-lathe, or the wheels of a clock.

36. *The power of a moving force is expressed by the weight it is capable of sustaining.* Thus, if a man, by his unaided strength, be able to raise a weight of two hundred pounds, he is

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Do machines add to the power? What purpose do machines serve? Illustrate this in case of raising a weight. In case of wind and saw mills. State the use of machines in regulating velocity. How is the power of a moving force expressed? Give illustrations.

said to have a power equivalent to this weight. So, if a steam-engine be equal to overcoming a resistance of fifty tons, it is said to have a power of fifty tons.

The mechanical force or momentum of a weight, is determined by multiplying it into the space through which it moves. So, also, the mechanical force or momentum of a power of any description may be ascertained by multiplying its equivalent weight into the quantity of its motion. When the momentum of the power acting through a machine is greater or less than that of the weight, the motion is accelerated or retarded in the direction of the power; but when the momentum of the power equals that of the weight, equilibrium is maintained between these.

Thus it will be understood what is meant when it is said, in the use of machines, *power is always gained at the expense of time;* for if, for instance, a small power act against a great resistance, the motion of the latter will be just so much slower than that of the power as the resistance or weight is greater than the power.

37. *Regulation of Force in Machines.* — In order for machines to operate successfully, it is necessary that their motions should be as uniform and regular as possible. For insuring such uniformity and regularity, various ingenious contrivances have been invented.

The Balance or Fly Wheel affords a common and effectual method of equalizing motion, especially in the heavier kinds of machinery. This usually consists of a heavy cast-iron wheel, fixed on the shaft near the crank, where the power of the engine or other force is applied. This balance-wheel serves as a magazine or repository for motion, overcoming by its mo-

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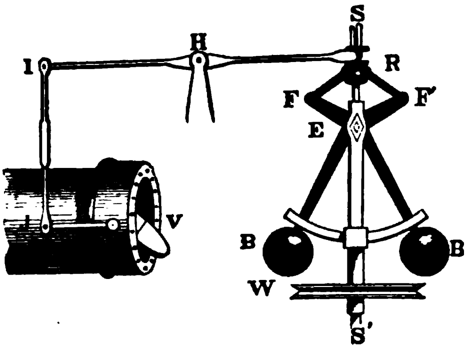
How is the momentum of a weight determined? The result when the momentum of the power is greater or less than the weight? What is meant when it is said that power is always gained at the expense of time? What is requisite for the successful operation of machines? Describe the balance-wheel and its use.

mentum, any slight irregularities in either the moving power or resistance.

38. *The Governor* is a highly ingenious device long since adopted for regulating mill-work, by regulating the quantity of the flow of water moving this. Its chief application has been, however, more recently to the steam-engine.

This contrivance is shown in Fig. 26, where B B are two heavy balls, attached to the ends of rods, B F, B F', jointed at E, and passing through a mortice in the vertical shaft, S S'. As this shaft revolves, centrifugal force causes the balls to fly out from it or spread themselves. At the same time the joints at F F' recede from each other, causing the ring at R, to which the arms, F R, F' R, are attached, and which is movable on the shaft, S S', to be drawn down. A lever, attached to the ring at R by a joint, has its end depressed as the ring descends on the shaft. This acting over the fulcrum at H, and through the joints at I and J, upon a second lever connected with the valve V, placed in the steam-pipe, causes this valve to open less or more, according to the distance at which the balls revolve from the shaft. At W is a grooved wheel fixed upon S S'. A cord leading around this connects with another grooved wheel on the main shaft or axle, whereby a speed is always transmitted to S S', proportionate to that of the machinery.

Fig. 26.



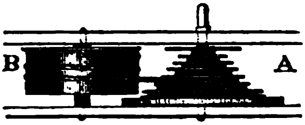
Thus, as the speed of the machinery increases, the balls sep-

Describe the Governor.

arate, the end of the lever at R is drawn down, and V closes, shutting off in a proportionate degree the steam, or other motive power. As this power diminishes the balls, B B, approach each other, R rises, and V opens accordingly; so rendering the power just *requisite* for giving a uniform and regular motion to the machinery.

39. *The Fusee, in watchwork*, is an instance in which a variable power is made to communicate a uniform motion. This may be effected by causing the velocity or leverage to increase as the intensity of the power diminishes. Let B, Fig. 27, represent the main-spring of a watch coiled up in a barrel, and connected with the fusee, A, by a fine chain. When the watch is first wound up, by winding the chain upon A, the spring acts with its greatest energy; but then the leverage of the wheel, which is its semi-diameter at the point where the chain unwinds from it, is least, being at the smaller end of A. This causes the chain to wind off from the spirals of the fusee upon the barrel slowly, increasing its rate as the diameter and leverage of A increase, and the force of B diminishes.

Fig. 27.

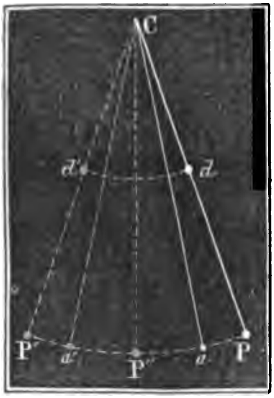


Thus, with a varying force, the revolution of the fusee is made uniform.

40. *The Pendulum* is a plummet or any heavy body suspended by a thread or small rod from a point of support, and, when disturbed, free to move about such a point as a centre. If a pendulum be drawn aside from its perpendicular or place of rest, and let fall, it will continue to vibrate in a vertical plane for several minutes, or even hours, until brought to rest again by the resistance of the air and friction at the point of support.

Describe the Fusee. What is a Pendulum? Describe the operation of this.

Fig. 28.



Let P'', Fig. 28, represent a pendulum suspended from the point C. If we bring this pendulum back to the point P, and let it fall, it will describe the arc P P', reaching P'' with such a velocity as to be carried forward and rise upon the opposite side of the perpendicular to P'; from this point it again falls, traversing the arc P' P'' P, and so continues its vibrations; each vibration describing a smaller arc than the previous, until the pendulum come to rest at P''.

The motion from P to P', and from P' to P, is termed a vibration, or *oscillation*, and from either of these points to P'', a *semi-oscillation.*

41. *All the vibrations of a pendulum of the same length are performed in equal times.*—Thus, in Fig. 28, if the ball P be let fall from that point at the same instant a second ball is set free at a, the declivity through which the former falls will be greater than that through which the latter moves; consequently, its accelerated force on reaching P'' will carry it forward through its vibration to P', in the same time that the ball at a moves through its vibration to a'; thus each ball will perform its vibrations through different arcs, equally distant from the point of support, in the same time. This, however, is not strictly true where the arc exceeds a certain limit, about 6°.

The times of the vibrations of pendulums of unequal lengths are as the square roots of these lengths. Suppose, in Fig. 28, two balls attached to the common centre, C, be let fall at the same instant from the points P and d; these will

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In the figure what constitutes a vibration, and what a semi-vibration? How do pendulums of the same length vibrate? State the proposition in regard to the times of the vibrations of pendulums of unequal lengths. Illustrate this.

perform their vibrations through the arcs P P′, and *d d′*, in unequal times. If *d* be four feet, and P nine feet from C, then will the times of their vibrations be as the square roots of these numbers; so that while *d* performs three vibrations, P will make only two.

42. The pendulum has been employed for *determining the figure of the earth, and as a standard of weights and measures.* It is the accelerating force of gravity which produces the vibrations of the pendulum; accordingly, the rate of these vibrations will increase with the increase of this force. Pendulums of the same length are found to have different rates of vibration at different points upon the earth's surface, and to vibrate in equal times require to be of varying lengths. Thus, a pendulum which performed its vibrations in one second at Paris, was found to require lengthening .09 of an inch in order to perform its vibrations in the same time at Spitzbergen. This variation is caused by a variation in the force of gravity, and this force of gravity is found to vary with the distance from the earth's centre (§ 11); hence, by means of the pendulum measuring the force of gravity at different points, the distance of these from the earth's centre, and, consequently, the figure of the earth, are determined. By this means the figure of the earth is found to be not a perfect sphere, but slightly flattened at the poles, so as to make its polar about twenty-six miles less than its equatorial diameter.

As the pendulum, in order to vibrate seconds in any place, must be always of the same length, it serves as an invariable standard of linear and cubic measures, and has been proposed as the universal unit of measure.[*]

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[*] The unit of *linear* measure is the yard, which is 1.086158 of the second's pendulum. The unit of measures of *weight* is the avoirdupois pound, $\frac{1}{62.5}$ of a cubic foot of pure water at its maximum density. In the United States, however, the pound troy (5762.38 grains) is the standard weight; and the

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Uses of the pendulum? How may it be used in determining the figure of the earth?

43. By far the most useful application of the pendulum is to clocks as a *measure of time*. A pendulum vibrating alone, independent of any mechanism, would measure the time which elapses during its oscillation; and to ascertain this would require only that an observer sit by and count the number of its oscillations. If the time of one oscillation were previously known, then the number of these performed in any interval would at once give the length of such interval. But, in order to supersede the attention and vigilance of such an observer, a train of wheel-work is placed in connection with the pendulum, the movement of which it regulates; and in connection with this wheel-work are fixed the dial-plate and the hands of the clock, by which the number of vibrations or oscillations of the pendulum which take place in a day, or in any part of a day, is indicated and registered.*

Fig. 29.

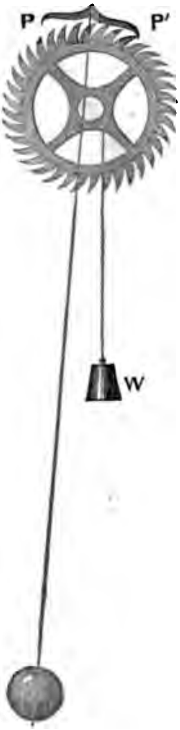

Fig. 29 shows the manner in which the pendulum regulates the movements of the clock. A toothed wheel is fixed upon an axis, around which winds a cord; to the end of this cord is attached a weight, W. Were there nothing to intercept, this weight would fall with an accelerated velocity, causing a proportionate revolution of the wheel; its progress, as that of the wheel, is, however, arrested by the pallets, P P', attached to the

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Winchester bushel (2150.4 cubic inches, or 77.6274 pounds of pure water) the standard for *dry measure*, while the English wine gallon (231 cubic inches, or 8.339 avoirdupois pure water) is the standard for *liquid* measure.

* Lardner.

The most useful application of the pendulum? State how this is applied as a measure of time. Explain the figure.

axis around which the pendulum vibrates. Thus, when the pendulum is in the position seen in the figure, the revolution of the wheel is arrested by the pallet, P′. As the pendulum swings back, P′ rises, and allows the wheel to move one tooth, when it is again arrested by the pallet, P, which descends and meets the tooth beneath it. Thus, with each oscillation of the pendulum a tooth escapes, and hence the term *escapement* applied to this contrivance. In this way a continued motion is given to the pendulum, which in turn regulates the movements of the clock. By interposing a sufficient number of wheels between the pendulum and the weight, clocks are made to run a month, or even a year, without winding.

44. *Friction* offers the chief resistance to moving bodies. This is of two kinds, *sliding* and *rolling*. When a heavy body having a polished surface is made to slide over another polished surface, the friction between the two surfaces is considerable. This is due to the minute irregularities on these surfaces. Oil, tallow, or plumbago, applied, serves to fill up and smooth these irregularities, and thus diminish friction. Friction produced by rolling bodies is far less than that produced from sliding bodies of equal weight; thus the same weight supported on wheels is moved with far less force than when resting on a drag. The friction of a machine is commonly estimated as equal to one third its power.

PRACTICAL PROBLEMS IN MECHANICS.

1. In a lever of the *first* kind, 6 feet in length, the power is 75 and the weight 150 lbs.; where must the fulcrum be placed that these may balance? (§ 24.)

2. If a lever of the *first* kind, 8 feet long, have its fulcrum 2 feet

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How does friction affect moving bodies? Kinds of friction? Explain the effects of friction and causes of these effects. How may this be overcome? What portion of the power of a machine is estimated as destroyed by friction?

from the weight at one end, and this weight be 450 lbs., what power at the other end of the lever will balance?

3. A lever of the *second* kind is 20 feet long; at what distance from the fulcrum must a weight of 80 lbs. be placed, so that it may be sustained by a power of 60 lbs.?

4. From a pole 8 feet long, resting on the shoulders of two men, is suspended a weight of 220 lbs., the point of suspension being 3 feet from the first, and 2 feet from the second man; what weight will each sustain?

5. In a lever of the *third* kind, 6 feet long, if a power of 150 lbs. be applied 2 feet from the fulcrum, what weight will it raise at the other end of the lever?

6. In the compound lever, Fig. 20, what weight at D will a power of 75 lbs. applied at A raise?

7. A power of 60 lbs. acts on a wheel 8 feet in diameter; what weight suspended from a rope winding round an axle 10 inches in diameter will balance this power?

8. In a system of pulleys shown at K, Fig. 22, what weight will a power of 100 lbs. sustain?

9. In the system shown at M, Fig. 22, what weight will a power of 50 lbs. sustain?

10. If a man has just strength sufficient to lift a barrel of flour, weighing 196 lbs., perpendicularly, so as to load it into a wagon 3 feet high, what weight could he raise by means of a plank, with one end resting upon the wagon, and the other on the ground 10 feet from this?

[In this case the power (196 lbs.) is to the weight as the height (3 feet) of the plane is to its length (10 feet).]

11. With what force will a weight of 1,200 lbs. press on an inclined plane, the length of which is 40 feet and the base 25 feet?

[The weight is to the pressure upon the plane as the length of the plane is to its base.]

12. Suppose a power of 60 lbs. be applied at the end of a lever 4 feet long, attached to a screw, the distance between the threads of which is $\frac{1}{3}$ of an inch; what weight will such a power sustain? (§ 33.)

13. If the length of a pendulum to vibrate seconds at Boston be 39,101 inches, how long must it be to vibrate half seconds? (§ 41.)

HYDROSTATICS.

45. HYDROSTATICS is that branch of natural philosophy which treats of the mechanical properties of liquids.

Liquids when at rest transmit their pressure equally in all directions. — It is this remarkable property which particularly distinguishes liquids from solids; for, while the latter press only downwards in the direction of gravity, liquids press in all directions,— downwards, upwards, and sideways. Thus, if the downward pressure of a liquid confined in a vessel be known for any depth below its surface, experiment shows its lateral and upward forces at this depth to be the same.

It is on this principle that the *hydrostatic paradox* is founded, which consists in the fact of a small column of water balancing a larger. Thus, in a teapot filled with liquid, the small column of this in the neck balances the larger in the body of the vessel, causing both to stand at the same level.

46. If a quantity of liquid be confined in a vessel, a mechanical force exerted on any portion of it will be at once transmitted through the whole mass. Thus, if a large and tight cistern filled with water have two small holes through remote parts of its top, upon forcing a cork into one of these, the pressure exerted upon the liquid directly beneath this will be instantly transmitted through the whole mass and felt at the other opening.*

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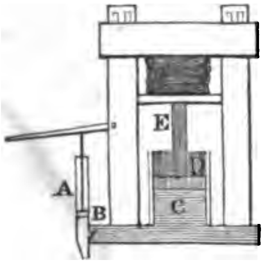
* Owing to the speed and facility with which liquids transmit a pressure upon them, tubes filled with water have been in some instances employed for transmitting signals between places separated by a distance of several miles.

Define Hydrostatics. State the proposition in regard to liquids at rest. On what principle is the hydrostatic paradox founded? Illustration? How is the pressure upon any portion of a mass of liquid transmitted? Illustration?

Fig. 30.



The Hydrostatic Press acts on this principle. This wonderful machine may be illustrated by Fig. 30. In a small cylinder, A B, moves the piston of a forcing-pump; this connects, through a tube leading from its side at B, with a much larger cylinder, C D. In this moves also a piston, having the upper end of its rod at E pressed against a movable plank or iron plate, surrounded by a strong framework; between this plank and the beam above is placed the substance to be pressed. By the action of the pump-handle water is raised into the cylinder, A, and on depressing the piston it is forced out through a valve at B and a pipe into the larger cylinder, C D, where it acts to raise the larger piston, and causes it to exert its whole force upon the objects confined between the planks or plates of the press.

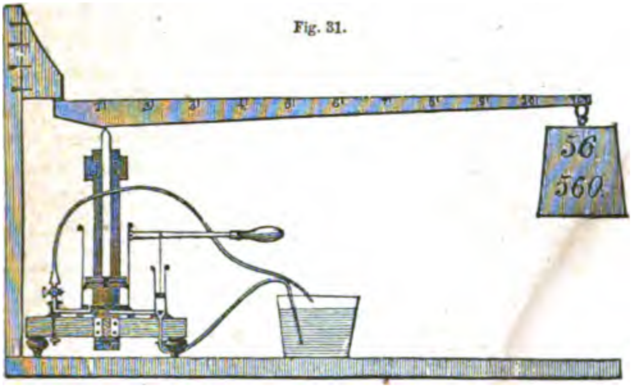
Now, as liquids transmit the pressure upon any portion of them in all directions, it follows that the pressure upon the piston at B will be transmitted to the piston in C D, increased in proportion as the area of the bottom of this exceeds the area of that at B.

Thus the power of such a machine becomes surprisingly great; for, suppose the area of the end of the larger to be one hundred times that of the smaller piston, then, if, by means of the lever-handle, a pressure of one hundred pounds be exerted upon the smaller piston, it will transmit this pressure to every equal area upon the bottom of the larger, causing this to exert a force at E of ten thousand pounds. By this machine, the force of a child exerted upon the lever-handle may be sufficient to crush the most stubborn objects.

Explain the action of the Hydrostatic Press. What is said of the force of this? Illustrate the ratio of the power to the resistance by the area of the two pistons.

Figure 31 exhibits a sectional view of another form of the Hydrostatic Press for measuring the amount of the force exerted. Here the liquid is represented as pumped from a vessel through a tube attached to the bottom of the smaller cylinder, and forced through a drop-valve in the bottom of the larger. A small pipe leading from the bottom of the larger cylinder is provided with a stop-cock, to which a hose may be attached and a stream of water thrown to a great distance by *hydrostatic* pressure. The end of a lever, placed beneath a bracket fastened to the wall, may rest upon the upper extremity of the piston-rod as a fulcrum. In this manner the pressure which the larger piston sustains may be determined.

Fig. 31.



47. The action of the Hydrostatic Press is based upon the principle that opposing forces are in equilibrium when their momenta are equal. Thus the momentum of the smaller piston may be regarded as the product of the space through which it moves into the area of its bottom; and the same also in regard to the larger. If the area of the larger piston be one hundred times that of the smaller, and the latter descend one inch, the

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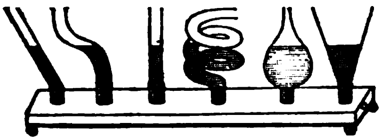
What does Fig. 31 illustrate? On what principle is the action of the Hydrostatic Press based? Illustrate this.

larger piston will be raised only $\frac{1}{100}$ of an inch. Thus, a small power upon the smaller piston may be made to balance a great weight upon the larger, by making the space moved over by the former as much greater than that moved over by the latter as the resistance or weight upon the larger exceeds the force exerted on the smaller piston.

48. *The surface of a liquid when at rest is level.* — The property in liquids of maintaining a horizontal surface is due to the slight cohesion among their particles, which allows them to yield to the tendency of matter to gravitate towards the earth's centre. Mountains and hills would flow down, and the whole surface of the globe become uniformly level, were it not for the cohesion among their particles, which is superior to their gravitating force.

This tendency of liquids to maintain a level, under all circumstances, may be illustrated by an arrangement seen in Fig. 32. Several glass vessels of different shapes are fixed in a stand, and connected by a pipe leading between their bottoms. If now water be poured into either of these, it will flow along the pipe, and be found to rise to the same height or level in each of the other vessels. Hence it is that aqueducts may be made to convey water over uneven surfaces, as hills and valleys, provided the point of delivery be not higher than the source from whence it flows. The play of the property in virtue of which liquids maintain their level, explains an infinite variety of important and interesting phenomena attending the circulation of water on the surface of the globe. By the nat-

Fig. 32.

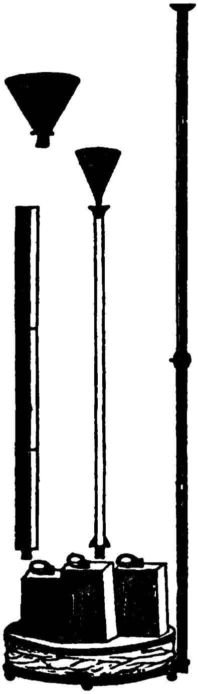


State the proposition in regard to the surface of a liquid at rest. Cause of this level? What does Fig. 32 illustrate? Why is it that aqueducts may be made to convey water over uneven surfaces?

ural process of evaporation, the clouds become charged with vapor, and are attracted by the lofty ridges of mountains, and all other elevated parts of the land around which they collect, and upon which they discharge their contents.

The water thus deposited upon the highest parts of the globe has a constant tendency to return to the general level of the sea, and, in finding its way thither, gives rise to the phenomena of streams, rivers, cataracts, lakes, springs, and all the infinite variety of effects attending the movement of water witnessed over the earth's surface. If the waters which fall from the clouds encounter a soil not easily penetrable, they collect in rills, and form streams and rivulets, and descend along the sides of the elevation, seeking constantly a lower level. These encounter in their course other streams, with which they unite, until they at length swell into a river, winding and widening in its course until its waters are again restored to the ocean, from whence they were taken. Throughout the whole of these phenomena the principle in operation is the tendency of liquids to maintain their level.*

Fig. 33.



49. *The pressure exerted by a column of liquid is as its height, and not as its quantity.*—This proposition may be illustrated by the *Hydrostatic Bellows*, Fig. 33. This instrument consists of two boards united by a flexible leather or cloth like a common bellows. A ver-

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* Lardner.

Explain the phenomena of the formation and flow of streams on the earth's surface. State proposition in section 49. By what instrument may this be illustrated? Describe the Hydrostatic Bellows and manner of its use.

tical tube attached to the side communicates with the interior space.

Experiment.—The bellows, when empty, may be loaded with weights. Water poured into the tube will be found to raise the upper board and weights, and, as the height of the vertical column in the tube is increased, so, in like proportion, may the weights upon the bellows be increased and supported.* In this experiment it matters not in regard to the size of the tube; the column in the forms represented in the figure, will exert the same pressure at the same height.† The upward pressure upon the upper board of the bellows, will be equal to the weight of a column of water resting on an area equal to this board, and of the same vertical height of the liquid in the tube.

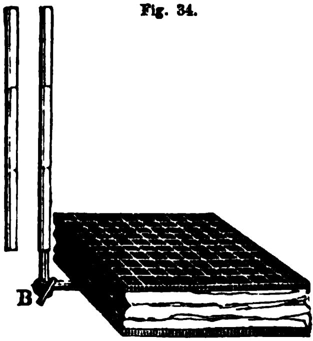

Fig. 34.

Fig. 34 exhibits another form of the same instrument, where the upper board is divided into one hundred squares, each having the same sectional area as the square tube containing the vertical column. Thus the proportional areas of the columns of the tube and bellows are definitely shown. At B is a three-way stop-cock, by which the communication between the tube and bellows is cut off; the water may be drawn from the bellows, and not from the tube, or from the tube, and not from the bellows; or it may be closed to either, while the tube is removed and another introduced.

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* A small quantity of water should be poured into the bellows, sufficient to separate the boards a trifle, before placing the weights upon these.

† Different forms and sizes of tubes, with their funnels, are represented in the figure. These tubes are made to screw together, so as to increase the height of the column.

To what is the upward pressure upon the upper board equal?

Experiment a.—That the pressure of a liquid is as its height may be illustrated by inserting a long tube in the end of a strong cask, and then pouring in water. As the cask becomes filled, and the liquid rises in the tube, a pressure will be exerted proportional to its height. In this manner the column of water contained in a small tube may be made to burst the strongest cask.

From the same cause, rocks are sometimes cleft asunder, and the sides of mountains forced off; water penetrating the earth to great depths, and filling cavities in these, and then rising in the entrance so as to exert a hydrostatic pressure equal to these results.

50. *The pressure upon the bottom of a vessel, containing a liquid, is not affected by the shape of the vessel, but is as the depth below the surface of the liquid.* Thus, whether the vessel have its sides diverging, converging or perpendicular, the pressure upon a bottom of the same area and depth will be equal.

This may be experimentally verified by the apparatus seen in

Fig. 35.

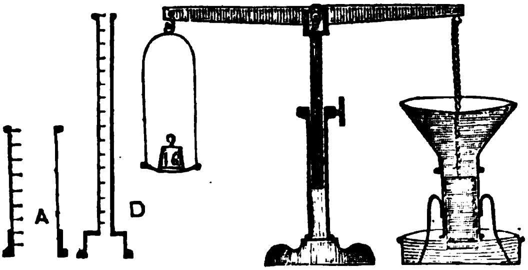

Fig. 35. Here a brass tube, mounted on a stand, has its lower extremity entering a basin of water; upon the top is screwed a

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How may the same proportion be illustrated by means of a strong cask and tube? Other illustrations? State the proposition in section 50. Explain the illustration of this proposition by the figure.

broad glass funnel; a plunger, nicely fitted to the brass tube, is attached by a small chain to the end of a scale-beam. When the funnel is filled with water to a given height, — say seven inches, — balance the scale-beam by weights placed in the opposite scale-pan; the pressure of the liquid upon the plunger, with this arrangement, may be thus ascertained. Now remove the funnel, and substitute the glass tube A, of the same sectional area as the brass one; fill this with liquid to the height of seven inches, and ascertain the pressure sustained by the plunger as before; remove this, and in its place substitute the small tall tube D, and fill to the same height, and ascertain the pressure upon the plunger, as in the two previous instances. In each instance the pressure of the liquid upon the plunger will be found the same; proving this pressure to be not affected by the shape of the vessel, but *as the depth below the surface.*

51. Since the pressure of liquids increases with the depth, a proper regard should be had for this in the construction of dams and embankments for confining water, causing these gradually to increase in thickness and strength from the top towards the bottom.*

Striking illustrations of the increase of pressure, in descending below the surface of liquids, are furnished by sinking bodies in the ocean. Thus, if an empty bottle, tightly corked,

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* The following table shows the pressure of water in pounds, at various depths:

Depth in feet.	Pressure per square inch.	Pressure per square foot.
	lbs.	lbs.
1	0.432	62 323
2	0.865	124.646
3	1.296	186.969
4	1.731	249.293
5	2.164	311.616
6	2.596	373.939
7	3.029	436.262
8	3.462	498.585
9	3.895	560.908
10	4.328	623.232

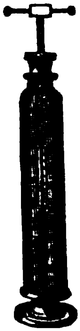
Where should this pressure of liquids be regarded?

be sunk, by weights attached, to a certain depth, — say five or six hundred feet, — it will be either crushed or the cork forced in; showing the enormous pressure to which it is subjected at that depth.

If a piece of wood, which floats on the surface of the water, be sunk in the same manner, the liquid will be forced into its pores by the surrounding pressure, so that it will be unable again to rise to the surface.

In plunging below a certain depth, divers often find the pressure so great as to rupture the more delicate vessels of the body, and do serious injury. It is said that the Greenland whale sometimes descends to the depth of a mile, but always comes up exhausted and spouting blood; showing that the pressure had so acted on the vessels as to cause them to discharge a portion of their contents into the lungs.

Fig. 36.



52. *Whether water be compressible or not* is a disputed question among philosophers. The following experiments, performed before the secretary and regents of the Smithsonian Institute, in 1849, go far towards substantiating the idea that it is non-compressible. Fig. 36 gives a partial view of the apparatus employed; and the manner of using this may be learned from the following

Experiment. — Fill with water the small bottle, to the tubular neck of which is affixed a minute scale. Place in the small cup at the top of this neck, a globule of mercury; lower this small bottle thus prepared into the strong glass cylinder; beside it may be placed a small *condensing-guage* for showing the degree of the compression. Fill the cylinder with water, and enter the screw, which works *air-tight*, through the thick brass cap. The water in the cylinder will undergo a powerful

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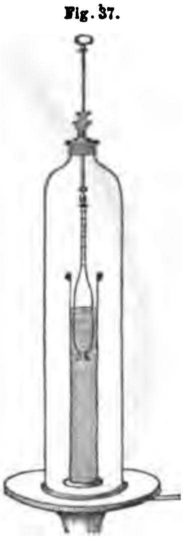
Give illustrations of the pressure exerted by liquids in case of a tight bottle sunk in the ocean. In case of wood. Results of diving below a certain depth? Case of the whale? What is said of the question in regard to the compressibility of water?

compression, which will act on that in the bottle, ***causing it to occupy less space***, as denoted by the sinking of the mercury in the tube or neck. This might be considered a satisfactory proof of the compressibility of the water in the bottle, and hence of liquids generally, were the experiments to end here.

Fig. 37.



Experiment a.— Now remove the small bottle from the cylinder, Fig. 36; invert and suspend it from a sliding-rod under the receiver of an air-pump, Fig. 44, in a manner similar to that seen in Fig. 37; draw up the sliding-rod so that the mouth of the bottle shall just clear the water in the jar. Exhaust thoroughly, so as to free the water, as far as possible, of its air; then let the neck into the water, and admit the air slowly into the receiver again. The bottle is now filled with water, nearly freed from air. Invert and place a globule of mercury in the cup, as before, and arrange the whole in the glass cylinder, as in the last experiment. Work down the screw-plug, and the water in the small bottle ***now undergoes no perceptible diminution of its volume;*** proving that in the celebrated experiment by Professor Oersted, so generally copied, ***it is the air in the water***, and not the water itself, which undergoes compression.

SPECIFIC GRAVITY.

53. If a solid body be accurately weighed in air, and then immersed in a vessel filled to the brim with water, and weighed again, it will be found to have lost in weight, or to be buoyed up by a force exactly equal to the weight of the water displaced by the solid, and which has flowed over the sides of the vessel.

Result of experiments? What is said of a solid body weighed in air and then in water? What is this difference in the weight of the body equal?

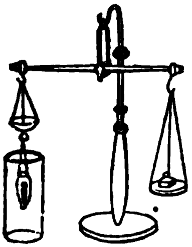
The difference, therefore, between the weight of the body in air and in water, will be the weight of a quantity of water of the same bulk as the solid body. If this quantity be heavier than the solid, it will float; but, if lighter, the solid will sink.

The specific gravity of a body is its weight compared with the weight of an equal bulk of some fluid. Pure water is usually taken as the standard for solids, and air for gases. If the weight of water be taken as unity, the weight of an equal bulk of a solid, heavier or lighter than this, will be expressed by a number greater or less than unity.

54. *To find the specific gravity of a solid body heavier than water.* — Ascertain its weight in air, and then again in water, and divide its former weight by the difference between the two weights; the quotient will express the specific gravity of the solid.

To find the specific gravity of a body lighter than water. — Tie to it any heavy solid, whose weight in air and water is known, and sink the whole in water. Weigh the compound both in air and water, and ascertain the loss of weight; then, knowing the weight lost by weighing the heavy body by itself in water, ascertain the difference of these losses, and divide the weight of the lighter body by this difference; the quotient will be its specific gravity. If the body be soluble in water, it may be covered with a coating of varnish, or be weighed in some other liquid whose specific gravity in relation to water is known, and which will not dissolve the solid. Fig. 38 exhibits a convenient arrangement of the scales, and the manner of suspending the body in water for finding its specific gravity. The body should be, if pos-

Fig. 38.



What do you mean by the specific gravity of a body? What is taken as the standard for solids? For gases? What rule for finding the specific gravity of a solid heavier than water? Rule for one lighter than water? What does Fig. 38 show? How should the body be suspended?

sible, suspended by a horse-hair, or fine waxed thread, where nice calculations are required.*

55. *To determine the specific gravity of a liquid.* — Ascertain the weight of a given quantity of pure water in a small vial, and then the weight of an equal quantity of the liquid in the same vial; divide the weight of the liquid by that of the water, and the quotient will be the specific gravity of the liquid.

There are various other modes of determining the specific weights of solids and liquids. We have only given such as are more simple and easy of performance.

The *Hydrometer* is an instrument used in commerce for determining at once the specific gravity of liquors, such as alcohol, acids, etc., and thereby the degree of their purity. The indications of this instrument all depend on the fact that a solid body, when it floats in a liquid, displaces a quantity of this equal to its own weight; consequently, if the liquid be heavier or lighter, bulk for bulk, than pure water, the hydrometer will sink or rise proportionally below or above the point at which it stands in the latter. †

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* Table showing the specific weights of certain solids at their greatest density.

Platinum,	22.06
Gold,	19.36
Copper,	8.87
Iron,	7.78
Tin,	7.29
Flint glass,	3.37
Marble,	2.83
Rock crystal,	2.68
Potassium,	.86

† Table showing the specific gravity of certain liquids at their greatest density.

Distilled water,	1.00
Mercury,	13.59
Concentrated sulphuric acid,	1.84

How may the specific gravity of a liquid be found? What is the Hydrometer? On what principle does it act?

Fig. 39 exhibits a common form of the hydrometer. This may be of glass or metal, and consists of two bulbs, to the larger and upper of which is attached a small stem, graduated from the top downwards. In the lower and smaller bulb is placed some mercury, or shot, sufficient to sink the bulb to a certain depth, and cause the stem to maintain a vertical position. The point at which the instrument stands in pure water, at its greatest density, is marked 0; that at which it stands in pure alcohol, 100. The adulteration of alcohol and other liquids lighter than water will add to their weight, which will be at once shown by the less depth to which the hydrometer will sink in these. For determining the specific gravities of acids and liquids heavier than water, a different graduation is required, and a small circular lead weight is slipped on the neck between the bulbs. Such is shown by Fig. 40.

Fig. 39.

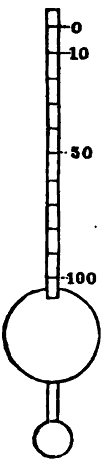
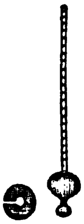


Fig. 40.



56. Bodies float on water agreeably with principles just considered. Thus, a ship laden with a heavy cargo is buoyed up from the fact that the weight of the water it displaces equals that of the entire ship and cargo.[*] So a tin pan or an iron boat floats,

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Fuming nitric acid,	1.45
Concentrated hydrochloric acid,	1.20
Pure alcohol,	.79
Ether,	.71
Sea-water,	1.02
Milk,	1.03
Naphtha,	.84

[*] By knowing the weight of a given bulk of water (a cubic foot), and then having the cubical dimensions of a vessel given, its tonnage may be readily determined. This may be found by subtracting the weight of the water dis-

Construction of the hydrometer? How used? Why do bodies float on liquids?

although made of materials whose specific gravities far exceed that of water, since they are so formed as to displace a weight of water equal to that of their own weight.

The human body, when the lungs are filled with air, is a trifle lighter than the same bulk of water, and, consequently, floats on this. In breathing out the air from the lungs it becomes heavier, and so to maintain itself on the surface requires a slight effort with the hands and feet. The bodies of some persons are lighter, bulk for bulk, than others; such are more buoyed up, and consequently swim with less effort. The bodies of drowned persons, after being beneath the surface a certain time, rise and float, owing to the inflation of the body by gases generated in decomposition.

LIQUIDS IN MOTION.

57. The branch of Hydrostatics which considers the flow of liquids through orifices in the sides of vessels, through pipes, in rivers, canals, etc., and their effects on solid bodies moving in them, is termed *Hydraulics*.

The various contingent causes which act to modify the flow of liquids render it not easy to bring this class of phenomena within fixed and prescribed rules. The analogy, however, between the effects of liquids and solids in motion, may be traced to a certain extent.

placed when the vessel is unladen, from the weight it will displace when loaded down to a certain point; the difference will give the weight of the cargo or tonnage it will carry. Camels, used in taking loaded ships over sand-bars, consist of tight and strong wooden boxes or tanks of large dimensions, attached while empty to the sides of the ship; the buoyancy of these prevents the vessel from drawing as much water or sinking as deep as it otherwise would.

State the case in regard to the human body. Why are some persons buoyed up more than others? Why do the bodies of drowned persons after a certain time rise to the surface? Define Hydraulics. What is said in regard to the flow of liquids?

The square of the velocity of a liquid escaping from an opening in the side of a vessel is as the depth below the surface.—This may be inferred from the fact already stated (§ 49), that the pressure of a liquid is as its depth. If several openings be made in the side of a vessel filled with water at the depth of one, four, nine, and sixteen feet, the velocities with which the liquid will escape from these will be in the proportion of one, two, three, and four. Thus, by knowing the velocity at any given depth, the velocity of the liquid at any other depth may be readily determined.

58. A liquid escaping from a reservoir, through a jet, opening upwards, would rise as high as the surface of the liquid in the reservoir, provided it encountered no friction or resistance of the air. The pressure of a liquid at any depth corresponds to the velocity of a falling solid at that depth; now, since a solid body acquires in falling from a given height a velocity sufficient to carry it up again to that height, so will a liquid issuing vertically upwards from a jet rise as high as the surface of the liquid in the reservoir, provided it be not obstructed by the causes just mentioned.

The rate of the flow of a liquid from a reservoir is greater through a short pipe, whose length bears a certain ratio to the orifice, than through the orifice alone.

59. *The resistance offered to a solid body moving through a liquid varies with the form of the solid.*—If the surface presented to the liquid by a body moved perpendicularly against it, be flat, the resistance will vary with the magnitude of the surface. If, instead of being presented perpendicularly to the liquid, the surface be presented obliquely with respect to the direction of its motion, the resistance will be diminished on two accounts; first, the quantity of liquid displaced will be less, and, second, the action of the surface in displacing it will have

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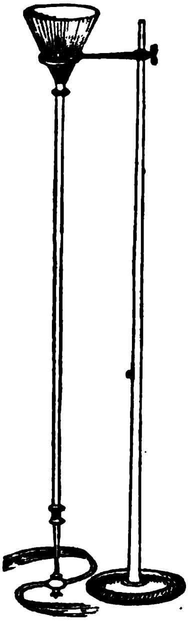
State the proposition in regard to the flow of a liquid from openings in the side of a vessel. Illustrate this. State the proposition in section 59. Illustrate this.

the mechanical advantage of an inclined plane or wedge, so that, instead of driving the liquid forward, it will, in some measure, push it aside.

The success in naval architecture depends upon a proper regard to these principles.*

60. The force of water in motion renders it highly serviceable as a motive power, and accordingly it is extensively applied in mechanical and manufacturing operations. Its application is usually to wheels, against which it exerts its force in various ways. The three common forms of water-wheels are the *over-shot*, the *under-shot*, and the *breast-wheel*. In the first, the water exerts its force upon the upper descending side of the wheel; in the second, upon the floats against which it flows upon the under side; in the breast-wheel, the water falls on a point nearly in a line with the axis, and acts chiefly by its weight.

Fig. 41.



A novel form of acquiring water-power has been, in some instances, resorted to by a contrivance known as Barker's Mill, where water is made to flow down a tube, and out through openings made on opposite sides near the extremities of two horizontal tubular arms. The unequal pressure exerted on the sides of these arms near their extremities by these discharges of the liquid causes them to revolve and turn a vertical shaft moving in the vertical tube, and to the upper end of which the machinery is attached. The principle of Barker's Mill

* Lardner.

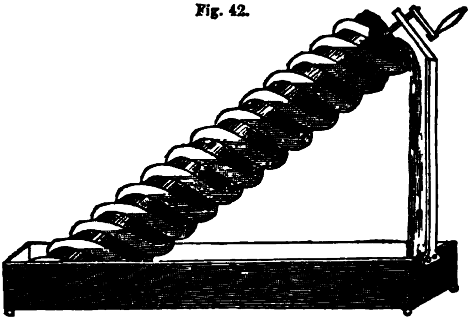
On what does the success of naval architecture depend? What is said of the force of water in motion? How is it usually applied? The kinds of water-wheels? How does the water exert its force on them? What is said of Barker's Mill? Its construction and manner of operating?

may be illustrated by a simple arrangement, seen in Fig. 41, where a revolving jet is attached to the lower extremity of a small tube provided with a funnel, and into which water is poured. The flow of water in opposite directions from the jet will cause it to revolve rapidly.

61. *Archimedes' Screw* is a hydraulic instrument invented by Archimedes, for draining certain portions of the valley of the Nile after the overflowings of the river. It was also used by the ancients, before the discovery of pumps, as a means of clearing the holds of vessels from water.

This machine is represented in Fig. 42, and consists of a tube wound in a spiral form about a cylinder. This cylinder is placed at a certain inclination, with its lower extremity resting in the water. As the cylinder is made to revolve, the end of the tube dips into water, and takes up within it a portion of this; this water continually flows to the under side of the tube, and, if the cylinder have not an angle with the horizon too great, the liquid will be raised and discharged out through the upper end of the tube.

Fig. 42.



PRACTICAL PROBLEMS IN HYDROSTATICS.

1. What pressure will a bottle, with a superficial area of 1 square foot, sustain when lowered into the sea to the depth of 500 feet? [The pressure will be equal to the weight of 500 cubic feet of water. See § 51.]

What is said of the Archimedes' Screw? Explain its construction and manner of operating.

2. If a cubical box, each side of which contains 9 square feet, be filled with water, and then a tube, inserted in its top, be also filled to the height of 25 feet, what pressure will be exerted on each side by the water in the tube alone, and what on the whole interior surface of the box?

3. What pressure will be sustained by a plank, 14 feet long and 16 inches wide, placed along the bottom of a flume 8 feet below the surface of the water?

4. What weight of water will a hollow sphere contain, the internal diameter of which is 10 inches, allowing a cubic inch of water to weigh .54 of an ounce troy?

5. If a stone weigh 12 lbs. in air, and 8.58 lbs. in water, what is its specific gravity? (§ 54.)

6. What is the specific gravity of a piece of ebony which weighs 14 lbs. in air and 8 lbs. in water?

7. A piece of iron weighed 18¼ ounces in air, and 16 ounces in a liquid; what was the specific gravity of the liquid? (§ 53.)

8. What is the weight of a block of granite 10 feet long, 3 feet wide, and 2 feet thick, the specific gravity of granite being 2.75, and a cubic foot of water weighing 1000 ounces avoirdupois?

9. What is the tonnage of a vessel which, upon receiving a full freight, displaces 2,420 cubic feet of water more than when empty?

10. What weight of mercury will an iron bottle holding 850 cubic inches contain?

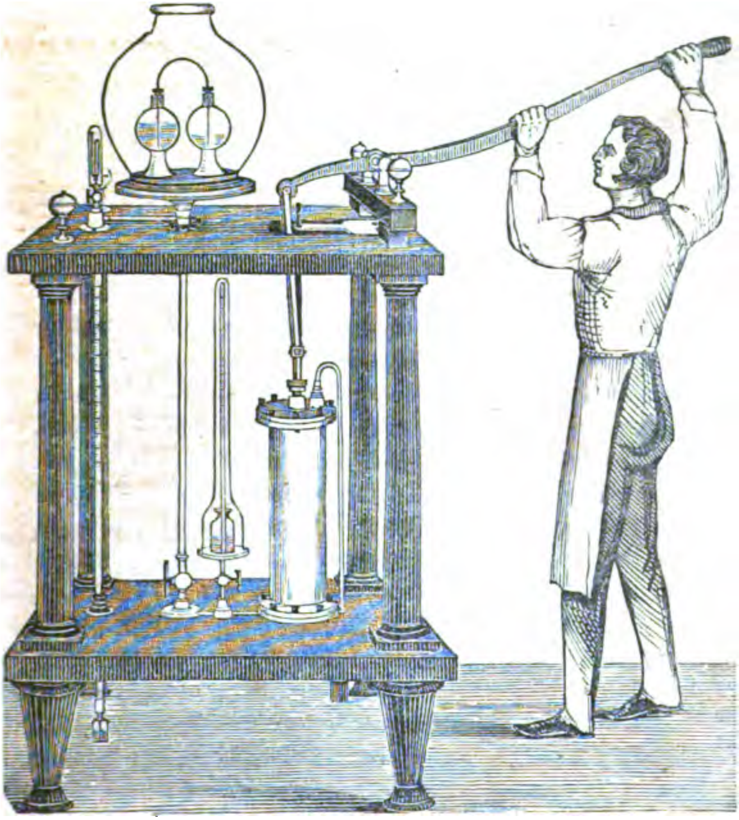
11. What pressure will the body of a pearl-diver sustain at a depth of 60 feet below the surface of the water, supposing the body to have a superficial area of 6 square feet, and the weight of a cubic foot of water to be 62½ lbs.?

12. Fishes have been drawn from the ocean at a depth of 2,800 feet; at this depth, what pressure would one, having a superficial area of 1 square foot, sustain?

INTRODUCTION TO PNEUMATICS, AND DESCRIPTION OF INSTRUMENTS.*

62. **That** class of fluids which are produced from solid and liquid bodies by the agency of heat are termed vapors. Such maintain their elastic form only so long as they are subjected

Fig. 43.



AMERICAN AIR-PUMP.

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* If desired by the instructor, this introduction may be omitted.

to the influence of heat in various degrees. Steam, for example, which is produced from boiling water, is readily condensed, and made to resume its liquid state upon the removal of the heat. Bodies, however, which maintain their elasticity at all temperatures, are said to be permanently elastic. Such are known as *Gases*.

Of elastic fluids *Atmospheric Air* affords one of the best examples, being, unlike steam and many of the gases, permanently elastic. This may, therefore, be employed to illustrate the mechanical properties common to all elastic vapors.

Air, in the strict sense, is a compound of the two gases, oxygen and nitrogen, mechanically mixed in certain definite and unvarying proportions — the term *atmosphere* being applied to the whole body of gaseous matter that surrounds the earth, including, besides air, watery vapor, and a variety of attenuated matter commingled.

The varied and important relations of the atmosphere to man's being and happiness render it especially deserving his careful study. By its vital energy he lives and moves, while its forces contribute in many ways to his convenience and comfort.

For illustrating successfully its mechanical properties, instruments of great delicacy and perfection of operation are required. Some of the more important of these we shall here explain, describing briefly their construction, uses, and liabilities, and the requisites for their successful operation. No written description of a pneumatic apparatus can, however, supersede the necessity of practical illustrations by the instructor.

63. *The Air-Pump.* — This instrument is employed for removing the air from the various forms of receivers, and is by far the most important instrument for illustrating the mechanical properties of air. A defect in this, or a want of the requisite

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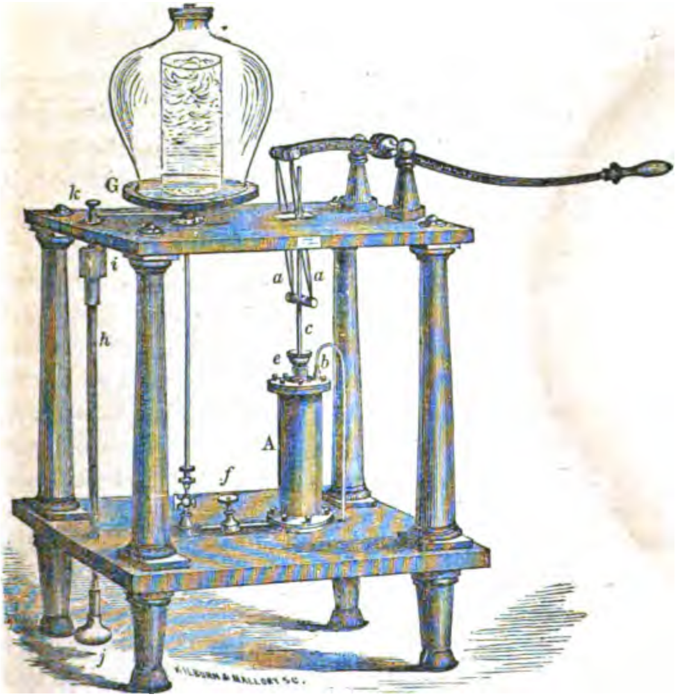
What is said of air as an elastic fluid? What is the composition of air? What does the term atmosphere comprehend? Why is the atmosphere deserving of careful study? What are necessary for illustrating the mechanical properties of air? For what is the Air-Pump employed?

skill on the part of the operator, will be often attended by a general failure, however perfect be the minor instruments of a pneumatic set. As elementary works upon natural philosophy seldom give any serviceable hints in regard to the liabilities of failure in the use of this, or practical directions how to remedy these when they occur, we have thought it advisable here to offer such as in our judgment may seem most needed.

Fig. 44.



64. *Description of the Air-Pump.**—Fig. 44 shows a form of the *American Lever Exhaust-Pump*, now generally used

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* If an air-pump or diagram is at hand, the pupil may describe the parts of the instrument from this.

What is said of its importance in pneumatic illustrations?

in the larger scientific institutions of the country, and recommended by its simple construction and the rapidity and perfection of its exhaustion. Within the barrel A, which stands upon the lower basement, moves a thin and nicely-packed piston. Upon the upper side of this piston is a small *drop-valve*, which plays freely up and down on the piston-rod, closing over two holes, which admit the air up through the piston. Beneath a small dome-cap, *b*, on the top of the barrel is placed a *clapper-valve*, also opening up and closing over two holes.* This valve is of fine leather, and is confined and kept in place by the dome-cap, which rests down upon a thin projection from the side of the valve. The third and only additional valve is placed at the bottom of the pump-barrel, and serves only as a guaranty against leakage in case of a defect in either of the valves above.

The *piston-rod*, *c*, which connects with the pump-lever by means of the *parallel rods*, *a a*, moves freely through an *air-tight* packing, *e*, at the top of the barrel, and also through a guide upon the upper basement. By this arrangement, and the valve upon the top of the cylinder, the piston is made to move in a vacuum free from the pressure of the atmosphere, and thus its ease and operation are greatly facilitated. Midway in the horizontal connecting tube which leads from the bottom of the pump-barrel, is the *vent-plug*, *f*. Here the air should always be admitted after exhaustion, and the oil poured in when necessary for lubricating the inner surface of the barrel. When

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* This, in the air-pumps recently constructed by Mr. Chamberlain, has been dispensed with, and a small *drop-valve*, so arranged as to preclude the possibility of failure in its operation, has been substituted. The dome-cap also closes over this valve by a single screw, and may be readily removed and replaced by the fingers. The whole is exceedingly simple and highly operative.

Describe the valves of the air-pump and their operation. What advantages from causing the piston to move in a tight barrel free from the atmospheric pressure?

desired, this plug may be removed, and various attachments of plates, hose, etc., made, as seen in Fig. 43. Upon the upper basement stands the *pump-plate*, G, which is screwed to a hub attached to the extremity of the upright connecting tube. Upon this plate are placed the various receivers to be exhausted. The *barometer-gauge*, *h*, employed for denoting the degree of the exhaustion, is a graduated glass tube, which is attached by a screw to the guard-box, *i*, just beneath the upper basement. To the lower end of this glass tube is screwed a small *mercury-cistern*, *j*, into which extends a steel tube tipped with platina, to prevent the entrance of air through the mercury into the barometer. A *screw-plug*, *k*, on the upper end of the guard-box, allows of various attachments of small gauges, etc., but *should never be used for venting or oiling the pump.*

A larger and more perfect form of the air-pump is shown by Fig. 43, while a smaller, yet highly operative instrument is represented in Fig. 164. All these are similar in their plan of construction and operation, and, although differing, according to size, in the rapidity, yet are equally perfect in the degree, of their exhaustion.*

65. *Theory of the Operation of the Air-Pump.*—The air-pump owes its power of exhausting to the expansive force of

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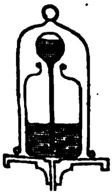
* Figure 45 shows an apparatus for determining the tightness of an air-pump, and the degree to which it will exhaust. This consists of a small glass bolt-head, with its stem just entering some colored liquid placed in a glass bottle beneath a receiver upon the pump-plate. As the pump is worked, the air will expand and flow out of the bolt-head, and upon again admitting it into the receiver, the liquid will rise and occupy the place of the removed air. If the exhaustion be good, a bubble of air no larger than a medium-sized shot will be found remaining in the bolt-head. If the pump and receiver be *absolutely tight*, the liquid will not rise in the tube after an exhaustion, until the air is regularly admitted. This is one of the most rigid tests of the air-pump known.

Fig. 45.



Point out the other parts of the air-pump. Explain the theory of exhaustion by means of the air-pump.

air. As the piston is raised from the bottom of the barrel, A, Fig. 44, it lifts the air above it, and forces it out through the drop-valve upon the top of the barrel; a vacuum is thus formed in the barrel below the piston, which causes the air in the receiver upon the pump-plate to expand and flow into the barrel. As the piston descends, this air in the barrel passes up through the drop-valve into the vacuum above caused by the descent of the piston. Upon raising the piston again, the air above it is condensed, and again forced out through the valve; and so the operation goes on — the air in the receiver becoming more rare with each rise of the piston, until the expansive force of the slight portion remaining is too feeble to raise the valves. Thus it will be seen that it is impossible, by means of the air-pump, to produce a perfect vacuum, since a portion of air must remain in the receiver, in order to expel the remainder.

66. *Directions for the use of the Air-Pump.*— Work the lever with a firm and steady hand, so as to bring the piston entirely up and down at each stroke. Keep this and the rod oiled with a moderate supply of the *best sperm oil.* An excess of oil, especially of an inferior quality, serves to clog and prevent the perfect action of the valves.

The piston should work free from atmospheric pressure; consequently a leakage of the upper valve from any cause may be readily known by a pressure upon the piston, and a tendency of the lever to rise. In such a case remove the dome-cap, and cleanse or renew the valve. The *drop-valve* upon the piston may be examined by carefully removing, in a similar manner, the top or cap from the barrel. With proper care these valves seldom become inoperative.

The glass receivers should be perfectly fitted to the pump-plate by a circular grinding with flour, emery, and oil; if so, to insure tightness, the plate will only require to be wiped over with an oily rag, before placing on it the receiver, for an exper-

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Why cannot a perfect vacuum be formed with this instrument?

iment. To guard against leakage, after a partial stroke of the lever, clasp the receiver with both hands, and give it a few circular turns of an inch or two back and forth, so as to crush out any particles of dust, and bring the two surfaces in immediate contact. Guard against scratching or marring in the least the surface of this plate.

Extreme caution is necessary in the use of mercury, lest it be drawn into the tubes, and, by its corrosive action on the brass, ruin the pump. The inexperienced would do well to dispense with those experiments requiring the use of this and strong acids about the pump. Directions for the use of these will be given as the experiments arise.

Should the platina he worn off the steel tube which enters the mercury-cistern, bubbles of air will be seen occasionally to enter the barometer, when the steel point will require to be tinned over or retipped with platina. The stop-cocks and screw-connections of a pneumatic apparatus should always be provided with oiled-leather washers. No washer is, however, required where the mercury-cistern screws upon the barometer, and the washer, where this attaches to the guard-box, should be but slightly oiled.

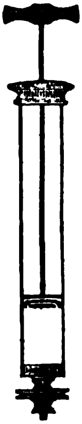
Should a leakage accidentally occur about any joint, it may be temporarily stopped by applying a trifle of thick paint.

Every article of a pneumatic apparatus should be kept free from dust and moisture; and after using, especially with liquids, should be wiped dry and smeared over with an oily cloth.

The taking to pieces and general repair of these air-pumps should never be attempted by those not familiar with their construction, for, although simple in form, yet they often baffle the skill of the amateur mechanic, unaccustomed to *air-tight* joints, to bring together the different parts when once separated. One may be a very "curious" mechanic, and able to dissect a manikin, clean a watch, or construct a puzzle-box, and yet not possess the requisite skill for filling a thermometer-tube, or adjusting the piston and valves of an air-pump.

67. *The Condenser.* — This, in its operation, is the reverse of the exhaust-pump, and is used for *forcing air into* vessels.

Fig. 46.



The simple form is shown by Fig. 46, and consists of a straight brass barrel, with a plunger nicely packed with leather, and having a valve in the lower part opening downward, while another valve, opening the same way, is attached to the lower end of the screw-plug, which enters the bottom of the barrel.

Theory of the operation of the Condenser or Force-Pump. — As the piston is drawn towards the top of the barrel, the air flows down through the valve into the space below; upon forcing the piston down, the air in the barrel is prevented from escaping through the piston by the closing of its valve, and is accordingly forced through the second valve, upon the screw-plug, into the chamber or receiver. The elastic force of this air closes the valve, and thus prevents its escape back into the barrel. As the piston rises, the barrel is again filled with air, which, upon the descent of the piston, is forced through the lower valve into the chamber, as before; and so the process may be continued until the air in the chamber has acquired a density and an expansive force truly surprising, as will be shown in the subsequent experiments.

These valves are simple in their construction, and when deranged may be easily repaired. By reversing the screw-plug, and also the parts of the piston which screw upon the end of the piston-rod, so as to bring the valves upon the upper side, this condenser may be readily converted into an exhaust-pump. No water should be allowed to remain in the barrel, as it will serve to stiffen and injure the packing. When, from any cause, the piston has been withdrawn from the barrel, some skill may be requisite for entering it again. *To enter the piston*, place the lower edge of the leather rim within the barrel; with the

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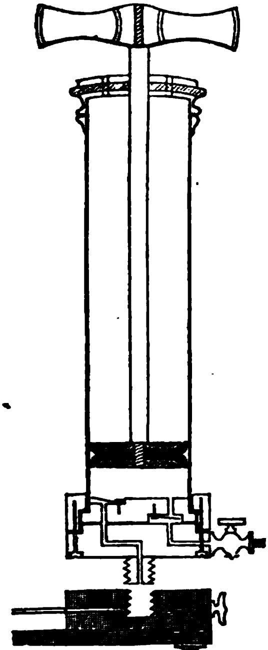
Describe the simple form of the Condenser. Explain the theory of its operation.

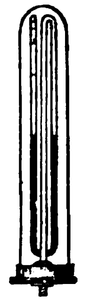
thumb and fore-finger press down the upper edge, and at the same time turn the piston, so as to *enter by degrees*, taking care not to let the edges of the leather get turned up.

Fig. 47.



68. *The Double-Acting Exhauster and Condenser*, Fig. 47, is a convenient instrument for the transfer of gases, etc., by exhausting from one vessel, and condensing into another. The piston, which is packed to work both ways, has no valve. In the bottom of the barrel are two clapper-valves, one opening up, and the other down. The barrel turns on an even and nicely-fitted plate at the bottom, to which it is tightly pressed by means of the two small screws which enter the binding-ring above. As arranged in the cut, it exhausts through the bottom hole, while it condenses out at the side stop-cock. Now turn the barrel so as to bring the valves each over the other opening, and the whole operation will be reversed.

Fig. 48.



69. *The Condensing-Gauge*, Fig. 48, is used in determining the degree of pressure to which air, steam and gas are subjected, and is screwed to the condensing-chamber, or other vessel into which these are to be forced. The pressure is indicated by the rise of the mercury in the sealed arm of the glass tube — the space of air being inversely as the pressure.[*]

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[*] Beware of mistaking this for the siphon-gauge below, and so connecting it with the exhaust-pump, as in such case an expensive mistake may occur by the mercury being drawn over into the tubes of the pump.

The Siphon Vacuum-Gauge, Fig. 49, may be used to show the degree of the exhaustion. The dark portion of the fine glass tube seen in the cut is filled with mercury. As the pressure of the air which forces the fluid into this arm of the tube is removed by exhaustion, the mercury falls in one and rises in the other arm, coming nearer to a level according as the space approaches a vacuum. This form of the gauge is used with the smaller air-pumps, and may be attached to the larger, at the screw over the guard-box. The strong glass cap, which covers this and the condensing-gauge, serves to protect them against breakage. The theory of these gauges will be explained in the subsequent experiments.

Fig. 49.

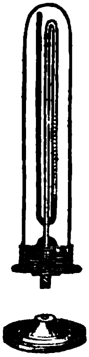
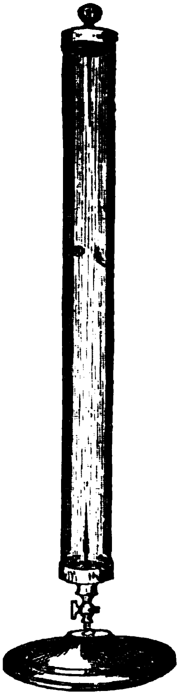


Fig 50.



70. *The Guinea and Feather Tube*, Fig. 50, used to illustrate the equal fall of light and heavy bodies in a vacuum, and also to furnish various electrical illuminations, is a long, brass-capped glass tube, used in connection with the air-pump. When screwed to the centre hole of the pump-plate, it should be with care, lest the stop-cock be wrenched off where it enters the hole. When the air is admitted after an exhaustion, the light bodies should be allowed to fall to the other end of the tube, lest they be injured by the rush of air through the stop-cock.*

71. The following cuts present accurate views of some of the more important articles employed for *forming connections* be-

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* These tubes may be used for showing the effect of condensed air on falling bodies, and are made for sustaining a pressure of four or five atmospheres.

tween the various parts of a pneumatic apparatus. To these we shall have frequent occasion to refer in the following pages.

Fig. 51.

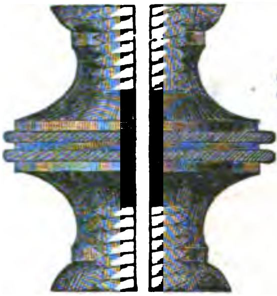


Fig. 52.

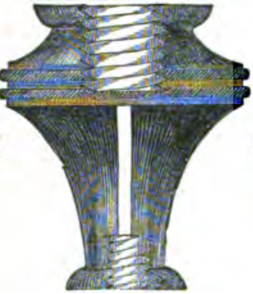


Fig. 53.

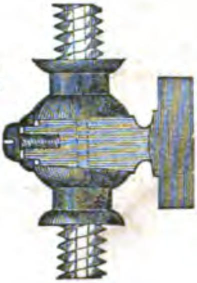


Fig. 54.

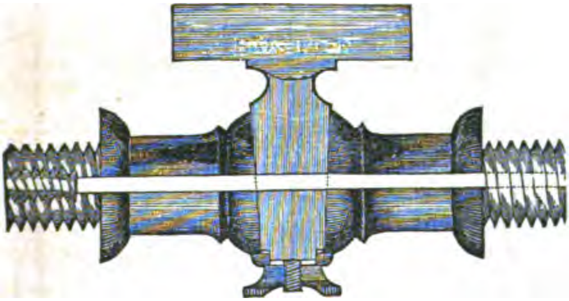


Fig. 55.

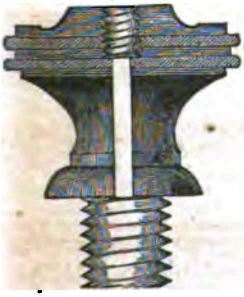


Fig. 56.

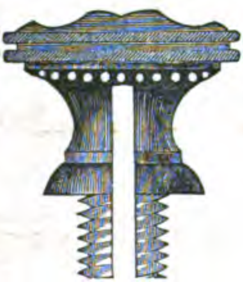
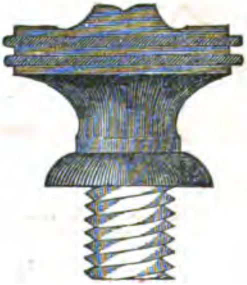


Fig. 57.



Figures 51 and 52 are much used for attaching the condenser, hose, etc. Fig. 53, small Stop-Cock. Fig. 54, large Stop-

Cock. Fig. 55, Connecting-Screw. Fig. 56, Guard-Screw. Fig. 57, Screw-Plug. Fig. 58, Gallows-Connector Exterior Screw. Fig. 59, Gallows-Connector Interior Screw. Fig. 60, Plate and Sliding-Rod. Fig. 61, and Fig. 62, Sliding-Rods with Screw-Plugs and Packing. Fig. 63, Flexible Rubber Hose.

Fig. 58.

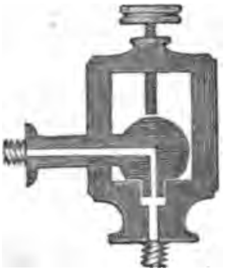


Fig. 59.

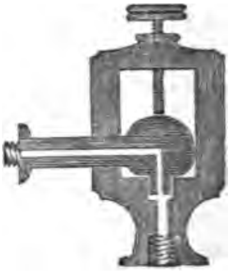


Fig. 60.

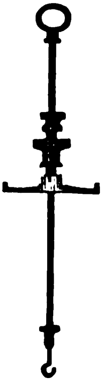


Fig. 61.

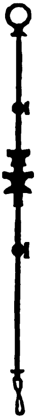


Fig. 62.

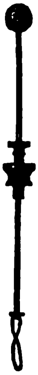
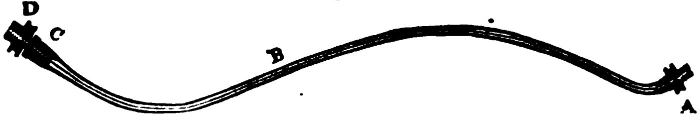


Fig. 63.



PNEUMATICS.

72. PNEUMATICS *explains the laws which regulate the flow and equilibrium of elastic fluids.*

Fluids are bodies whose particles glide easily among themselves, and tend readily to a level or equilibrium. These are divided into two classes, elastic and inelastic fluids. To the former belong the gases and vapors; to the latter, water and other liquids. Elastic fluids are also comprehended under two divisions; those like atmospheric air, many of the simple gases, which can never, by any known agencies, be made to yield up their elasticity and assume a different form, and those like steam, carbonic acid, etc., whose elastic natures depend on the circumstances of heat and pressure.

Air and steam are the elastic fluids chiefly employed as mechanical agents, and will, therefore, be taken to illustrate the general principles of pneumatics common to all elastic fluids.

Atmospheric air is a thin, transparent fluid, which surrounds the earth, extending up from its surface to the distance of about forty-eight or fifty miles. By virtue of one of its constituent elements, it feeds the lungs, and gives vitality to the whole animal creation, while it serves an agency scarcely less important in the sustenance and growth of the vegetable kingdom. The constitution and vital qualities of air are, however, proper subjects for chemical inquiry, its mechanical properties alone claiming attention in this connection. The *obvious* properties of air, such as its materiality, fluidity and elasticity, may be satisfactorily illustrated by a variety of mechanical contrivances. These, with the principles they explain, we shall

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Define Pneumatics. What are fluids? How are fluids divided? What elastic fluids are chiefly employed as mechanical agents? What is atmospheric air? What is said of the relations of air to the animal and vegetable creation? What are the obvious properties of air?

endeavor to present clearly, yet concisely, in the following experiments.

MATERIALITY OF AIR.

73. The proofs of its materiality are various, and among these is that furnished to the eye.

Air is visible. — When seen through a great extent, as when we gaze at the firmament or a distant mountain, these present a faint blue, which is the color reflected by the great body of intervening air. Within a limited space, the light reflected is too feeble to give it color, and hence it is usually regarded as invisible. This is true of many of the more dense semi-transparent bodies. A glass basin of water, for instance, dipped from the ocean, appears colorless, while the same liquid seen through a great depth "off soundings" shows a peculiar dark green color. Thus, *color*, which is a characteristic of matter, belongs to air, in common with more dense bodies.

When a body in motion meets with and sets in motion another body, the former loses a force equal to that which it imparts to the latter. This resistance of the body struck is termed its *inertia* (§ 4). Inertia or resistance is a property which can be predicated only of matter. Whatever, therefore, resists or destroys the force of bodies is itself material.

74. *The inertia of air* shows itself in a variety of ways. If we stand upon the outside of a rail-car in the calmest day, the displacement of the air by our bodies, as we are borne through it, will offer a resistance equal to a stiff breeze blowing in the opposite direction. So, when we attempt to carry a board, or any broad surface, exposed to the air, in the direction we are moving, a powerful resistance is offered by this.

Experiment. — Place the *float-wheel*, Fig. 64, on the pin, so that the surface of the floats shall be in a line with the handle. Give motion to the wheel, and it soon ceases

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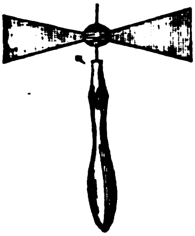
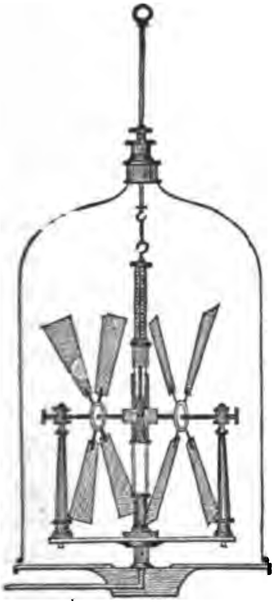
Is air material? The first proof stated of this? What illustrations given? Is inertia a property of material bodies? Has air inertia? What illustrations given? State the experiment with the float-wheel, Fig. 64.

Fig. 64.



to revolve, owing to the resistance offered by the air. Now place the hub on the pin, so as to bring the floats *edgewise* to the direction of motion, and the great diminution of the surface opposed to the air will cause the wheel to continue its revolutions much longer than before.

Fig. 65.



One of the most satisfactory proofs of the materiality of air, from its resistance to moving bodies, is afforded by an arrangement seen in Fig. 65, and known as the *vane and mill.* Two float-wheels are made to revolve independent of each other, and precisely alike. Power is communicated to each, at the same instant, by means of a rack, which plays into a small pinion upon the shaft of each wheel. This rack is on a tube, which may be drawn up by means of a sliding-rod, and, when released, is suddenly forced down by a spiral spring within, giving a rapid motion to the wheels.

Experiment a. — Screw the centre-post to the hole of the pump-plate, and arrange the floats so that those of one wheel shall stand edgewise, and those of the other facewise, to the direction of motion. Cover with a bell-glass, having a brass cap and sliding-rod; attach the loop upon the end of this rod to the hook at the top of the sliding-tube. Draw up, and suddenly depress this, which will give motion alike to both wheels; but, owing to the presence of the resisting air, the one

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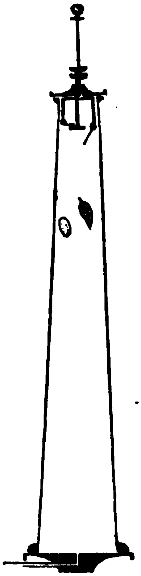
How may the materiality of air be shown with the vane and mill (Fig. 65)?

facewise will revolve only about one eighth as long as the one edgewise to the direction of motion.

Now work the air-pump and remove the air from the bell-glass, and again give motion to the wheels, when both will be found to revolve very nearly alike, and much longer than either did before; thus clearly proving that *air is a resisting, and of course a material body.*

It is the inertia of the air acting upon the wings of the feathered and insect tribes that enables them to fly and transport themselves through it from one place to another. This may be shown by placing some flies or other winged insects beneath the receiver of the air-pump, and removing the air, when any efforts to rise by a use of the wings will be seen to be unavailing.

Fig. 66.



75. Gravity acts alike on all bodies, light and heavy, and, were it not for the resistance offered by the atmosphere, a floc of cotton and a bullet let fall together from the same elevation would reach the ground in the same time.

Experiment. — Let the tall *Guinea and Feather Glass*, Fig. 66, be well fitted to the pump-plate, and on each of the four small tables, beneath the brass plate which covers the top, place a dime and feather. Before exhausting the air from the glass receiver, turn the sliding-rod and button which supports these tables, until one of them drops, and lets fall its dime and feather; while the former, by its weight, overcomes the resistance of the air, and falls rapidly, the lighter feather makes a tardy descent. Now produce a partial vacuum, and let drop a second table; the removal of a portion of the resisting air will make the differ-

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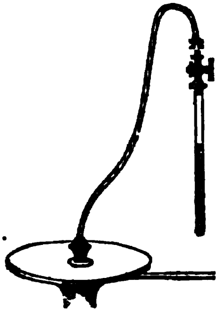
How is it that birds are enabled to fly? Illustrate in the case of flies and winged insects. State the experiment with the guinea and feather glass. What does this prove?

ence less marked than before. Continue to exhaust, and the third will fall still more nearly together; form a vacuum, and the fourth pair will show no perceptible difference in the time of their descent.*

Fig. 67.



76. *The fall of liquids in a vacuum*, and the agency of the atmosphere in breaking the force of rain and hail as they descend from great elevations, may be illustrated by the *Philosophical Water-Hammer*, Fig. 67. This is a strong glass tube, hermetically sealed at one end, and provided with a cap and stop-cock at the other.

Experiment. — Remove the stop-cock, and fill the tube about half full of clear water; replace this, and, by means of the coupler and hose, figures 51 and 63, connect with the air-pump, and with the stop-cock open, exhaust thoroughly, occasionally shaking the tube a trifle, to "churn out" the air that may still remain between the particles of the liquid. Turn the stop-cock and detach from the hose. If now the tube be

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* A more simple and economical mode of illustrating the same principle is by means of the long *Guinea and Feather Tube*, Fig. 50. Screw this to the centre hole of the pump-plate; or, if too long and heavy, connect with this by means of the coupler and hose, figures 51 and 63. Before exhausting, suddenly invert the tube, and mark the difference in the fall of the light and heavy bodies. When a vacuum has been obtained, turn the stop-cock and remove from the pump, and again invert as before, when the difference in the fall of the light and heavy bodies will, as in the last experiment, be imperceptible. Now admit the air, and attach the condenser, Fig. 46, by means of the coupler last used, and condense forty or more strokes, according to the size of the tube. Close the stop-cock and remove the condenser. The tube will now contain from two to four atmospheres, and the greater density of the air will be plainly visible in the greatly retarded fall of the light bodies; thus most satisfactorily showing the materiality and resistance of air.

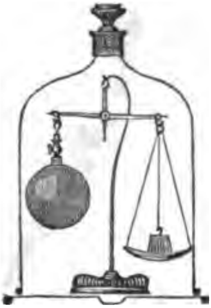
What is the Philosophical Water-Hammer? Give the experiment with this.

held at an angle of forty-five degrees with the floor, and jerked so as to throw the liquid up two or three inches, meeting with no atmospheric resistance, it will fall with a hard, clinking sound, and with the force of lead.

From this experiment we learn one of the beneficial effects of the atmosphere, in relieving the fall, and preventing the injurious effects which might otherwise result from the descent of rain, etc.; for, were there no atmosphere to impede the fall, such bodies would strike the earth with the force of shot fired from a gun.*

77. *The Buoyancy of Air.* — Air being, like water, a material fluid, tends like that to buoy up bodies in proportion to the amount displaced; hence, light and bulky bodies, as loose feathers, cotton and wool, *weigh less* in air than in a vacuum.

Fig. 68.



Experiment. — Balance the thin glass globe by a weight, and, with the stop-cock closed, place the scales on the pump-plate, and cover with a receiver, as seen in Fig. 68. Exhaust the receiver, and the glass globe, which was before sustained in part by the fluid air, will be now found to preponderate and weigh more than in the air. Now remove the globe, and balance in its place a bunch of feathers or cotton, and again exhaust the receiver, when these

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* A cheaper yet less perfect form of the Philosophical Water-Hammer, exhausted by heat and made permanently tight, is sold at the shops. Jerk the tube with caution and at an angle, lest the force of the liquid break through the bottom. No amount of exhaustion can free a vessel in which a liquid is confined from a *vapory atmosphere;* and, as a vacuum is approached, ebullition goes on rapidly, although the liquid be near the freezing-point.

What may we learn from this experiment? What is said in case there were no atmosphere to impede the fall of rain and hail? What is said of the buoyancy of air? Give the experiment for showing its buoyancy.

will be found like the glass globe to indicate an increase of weight; thus proving the truth of the common assertion that, by the ordinary tests, "a pound of lead weighs more than a pound of feathers."

Experiment. — This same principle may be illustrated without the use of the air-pump. Suspend, in the place of the glass globe in the last experiment, a small, light rubber bag provided with a stop-cock; balance this accurately, and then, with the condenser and coupler, Figs. 46 and 51, inflate the bag, close the stop-cock, and again suspend from the scale-beam, when it will be found to have lost in weight, or be *buoyed up* by a force equal to the additional volume of air it now occupies.

78. *Air is impenetrable.* — This is perhaps, if possible, a more convincing proof of its materiality than any previously offered. It is a property of matter that no two bodies can occupy the same space at the same time. To this proposition air conforms as strictly as lead or water. Attempt to force these into a vessel filled with air, and, although this may contract its limits and retire before the more dense intruders, yet still the space *it really* occupies can never be entered by a second body.

Experiment. — Plunge an inverted tumbler or tall glass jar in a vessel of water; the materiality of the air confined above the water will prevent this from rising and filling the jar or tumbler.

The *Diving-Bell* acts upon this principle of the impenetrability of air. This is a large bell-shaped receiver, made strong and tight, and of sufficient weight about the opening to cause it to sink to a great depth in water, and retain its proper position. In the upper part are provided seats for the workmen, while two tubes enter, one at the bottom, the other at the top; the former connecting with a force-pump upon the wharf or-

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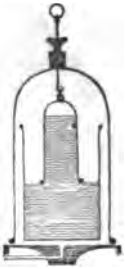
Is impenetrability a property of matter? Is air impenetrable? What is said when we attempt to force other bodies into a space filled with air? Give the experiment illustrating this. On what principle does the Diving-Bell act? Describe the Diving-Bell.

deck of the vessel, through which fresh air is supplied to the men in the bell, while the latter serves as an escape for the impure air. When lowered into the water, the air, as in the experiment just given, precludes the entry of the water, and allows the workmen, although at a great depth below the surface, to operate without inconvenience. Again, if the air be removed from a vessel before it is plunged in water, as in the last experiment, the water will then enter and fill the entire space.

Fig. 69.



Experiment. a.—Suspend a small bell-glass beneath a larger, by means of a sliding-rod, and place them on the plate of the air-pump over a jar of water, as shown in Fig. 69. Lower the small bell upon the water; this refuses to enter the bell, owing to its being preöccupied by a second body—air. Raise now the bell, and exhaust the receiver, and again lower into the jar, when the water readily enters and fills it.*

THE WEIGHT AND PRESSURE OF AIR.

79. Since air is material, it possesses weight, like other more dense bodies; but, owing to its extreme thinness and transparency, this property in air becomes less obvious than in the grosser forms of matter. By the aid of skilful mechanical contrivances, the weight of air may, however, be determined with as much precision as that of water or lead. The ancients, although acquainted with the fact that air has weight, still

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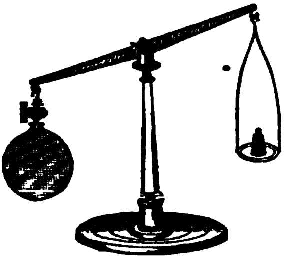
* A small bubble will be found in the upper portion of the bell-glass, however thorough be the exhaustion, owing to the impossibility of an entire removal of the air by any mechanical contrivance. This bubble of air will vary in size, according to the degree of the vacuum.

State Experiment *a.* Has air weight? Why is not this property of air more obvious? Can its weight be accurately determined?

knew little of its mechanical effects in producing the common phenomena of every-day occurrence. Thus, the cause of the rise of water in pumps and other tubes was thought to be *suction*, or *the abhorrence which nature has of a vacuum;* hence, practising upon such vague and absurd maxims, they were constantly liable to those ridiculous blunders and expensive mistakes which always accompany ignorance of physical laws. Galileo with his pupil Torricelli were the first to discover the mechanical agencies of air in the rise of liquids, etc. Some engineers, employed at Florence in sinking pumps, had occasion to construct one to raise water from an unusual depth. Upon working it, they found the water would rise only to a height of about thirty feet. Galileo, the most celebrated philosopher of the day, was consulted as to the difficulty. Having his attention thus called to the point, his investigations with those of Torricelli soon disclosed the cause, and, furthermore, produced the barometer as the measurer of the atmospheric weight. From these discoveries, *Pneumatics* as a science may be said to date. The following experiments, properly performed, will give some ideas of the weight of the air, and the surprising force with which it presses on bodies at the earth's surface.

Fig. 70.



Experiment. — *To weigh a quantity of air.* Take a pint or quart flask provided with a stop-cock; connect this with the air-pump, and remove the air. Then close the stop-cock, and suspend the flask from a delicate scale-

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What is said of the knowledge of the ancients in regard to the mechanical effects of this property of air? To what cause did they attribute the rise of liquids in pumps, etc.? Who first discovered the real cause of these phenomena? Anecdote in respect to the engineers and Galileo? Give the experiment for determining the weight of air by exhaustion.

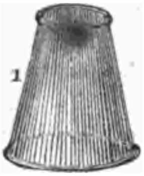
beam, as shown in Fig. 70. Now balance the flask by small weights, and when this is done admit the air into this. The side of the beam from which the flask is suspended will now be found to preponderate. Add small weights to the opposite scale-pan until the equilibrium is restored. These weights will indicate the weight of the admitted air, or of that removed by the air-pump.

A quart of air, at the ordinary density, weighs nearly *seventeen grains*. Attach now to the flask, by means of the coupler, Fig. 52, the condenser, and force in one or two additional atmospheres; a marked increase in the weight of the flask will now be perceptible.*

80. Since so small a quantity of air has appreciable weight, the pressure of the entire column reaching upward through the whole extent of atmosphere, and resting on a given surface, must be enormous. This is equal to about *fifteen pounds* on the square inch, or *two thousand one hundred and sixty* pounds on the square foot.

Experiment.— *To prove atmospheric pressure*, place on the pump-plate the *Hand-Glass*, Fig. 71, and cover the smaller end with the palm. Exhaust, and as the air or support is taken from beneath, the weight of the atmospheric column resting down from above will press the hand firmly to the glass with a force of from fifty to eighty pounds.

Fig. 71.



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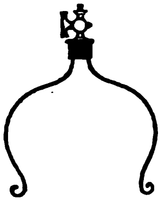
* Table showing the specific gravities of various gases, with the barometer at 30 inches, and Fahrenheit's thermometer at 32°:

Air,	1.00	Ammonia,	0.59
Oxygen,	1.10	Carbonic Acid,	1.59
Hydrogen,	0.06	Prot. Oxide Nitrogen (Exhilarating Gas),	1.52
Olefiant Gas,	0.97	Chlorine,	2.47
Phos. Hydrogen,	1.21		
Nitrogen,	0.97		

How by condensation? What is the weight or pressure of the air on a square inch of surface? A square foot?

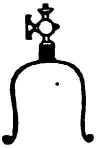
Fig. 72.



Experiment a. — Tie over the mouth of the *Bladder-Cup*, Fig. 72, some highly elastic sheet-rubber, and screw, by means of the connecting-screw, to the centre hole of the pump-plate. Exhaust, and the *pressure of the external air* will force in the rubber so as to form a perfect lining for the glass.

Experiment b. — Connect the *Cupping-Glass*, Fig. 73, with the air-pump, by means of the rubber hose, and place it on the arm or any part of the body where a slight puncture has been made in a vein. Exhaust, and the pressure of the air within, by its elastic force, will swell the skin, and cause the blood to spirt freely from the punctured vein.

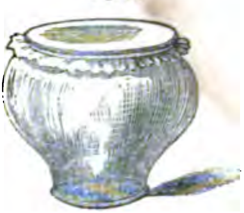
Fig. 73.



Remark. — It is by thus removing the external pressure that the leech is enabled to draw blood through the pores of the skin. All instances of *suction* are thus produced by the removal of the pressure of the external air by the air-pump, the mouth, etc.

Experiment c. — Over the larger end of the *Bladder-Glass*, Fig. 74, draw tightly and evenly a piece of moistened hog's bladder, and fasten under the flange by means of a solution of gum-arabic or a string. When thoroughly dry, place on the pump-plate, and exhaust. The removal of the air or support from beneath will cause the weight of the external column to *crush in the bladder with a deafening report.*[*]

Fig. 74.

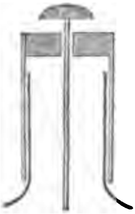


[*] Should the bladder be so strong as to sustain the atmospheric pressure, a slight puncture with a pin will cause it to collapse as above. By inverting after the bladder is removed, this may be used, as in experiment, for a hand-glass.

Give Experiment. Give Experiment *a*. State the experiment with the cupping-glass. Experiment with the bladder-glass.

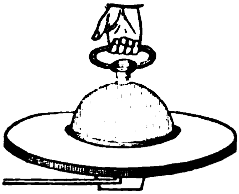
Experiment d.—Attach to the centre hole of the pump-plate the guard-screw, Fig. 56, and on the plate place a thin glass *bursting-square*, having a brass cap with a valve sealed upon the neck, like that seen in Fig. 75. Cover with a bell-glass, and exhaust; the valve rises to let out the air. When a vacuum has been formed, admit the air again to the bell, and the valve closes tightly and preserves a vacuum in the square, which, having nothing within to counterbalance the external pressure, is ***crushed in by the atmospheric weight.****

Fig. 75.



81. *Experiment*—Place one hemisphere of the *Magdeburgh Cups*† on the pump-plate, as seen in Fig. 76, and exhaust; the pressure of the atmosphere will hold it firmly to the plate.

Fig. 76.



Experiment a.—Remove the lower handle from the *Magdeburgh Hemispheres*, Fig. 77, and screw the stop-cock to the centre hole of the pump-plate; turn the upper hemisphere back and forth a trifle to insure a perfect contact of the two surfaces,

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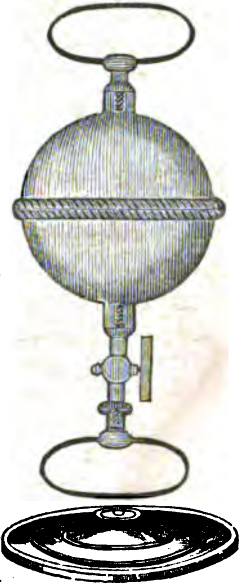
* Care should be taken against scratching the plate when wiping from it the fragments of glass. As this experiment incurs some trouble and risk, and can be seen only by those immediately about the pump, it is hardly advisable to introduce it in ordinary lectures. The same cap and valve may be used with any number of squares.

† These cups were invented and first used by Otto Guerick, the inventor of the air-pump, and named from the city where first used. An experiment was performed by the discoverer before the royal household with a pair of these cups, which were three feet in diameter. When exhausted of air, twenty strong horses attached, and drawing in opposite directions, ten upon each side, are stated to have been unable to separate the cups, so great was the force of the pressure of the air by which they were held together.

Why is a thin square bottle crushed in when the air is removed from its interior?

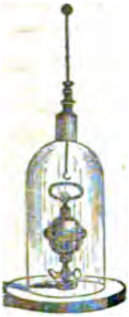
Fig. 77.



and then form a vacuum. With the stop-cock closed, remove and replace the handle.

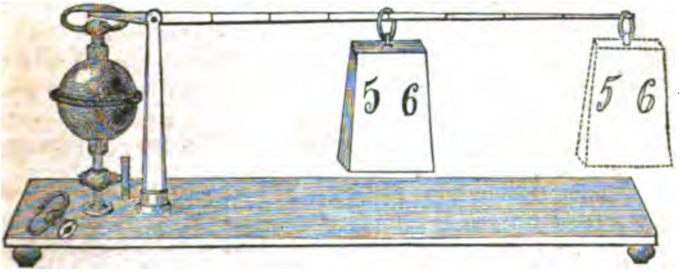
These hemispheres, of five inches diameter, will now be *pressed together by the force of the atmosphere*, so that two strong men may not be able to separate them.

Fig. 78.



To prove that these hemispheres *are* now held together by the force of the air, let them be again screwed to the pump-plate, and covered by a bell-glass provided with a sliding-rod and hook, as seen in Fig. 78. Attach the hook of the rod to the handle, and exhaust the bell-glass; the upper hemisphere may be now readily raised from the lower. Replace it carefully, and admit the air into the bell, when the hemispheres will be again held firmly together.

Fig. 79.



Experiment b. — With the Magdeburgh Hemispheres exhausted as above, screw to the brass socket of the basement,

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What is the result in removing the air from within the Magdeburgh Hemispheres? How can it be shown that it is the pressure of the air which holds these together so firmly? Give the experiment for showing the amount of pressure on these.

and arrange other ways, as shown by Fig. 79. In this way the pressure of a column of air with a base of the area of either hemisphere may be ascertained.*

82. As has been already remarked, the pressure of the atmosphere is equal, at the level of the ocean, to a weight of fifteen pounds to the square inch, and hence that sustained by the body of a common-sized man, comprising two thousand square inches, must be about *fifteen tons*. Such a weight resting on bodies might, at first thought, be expected to crush them, whereas we find those of the most delicate texture unaffected by it. This arises from the circumstance of the pressure on every side being equal, and, therefore, producing a mechanical equilibrium. Under ordinary circumstances, the pressure upon the external surface of the body is exactly counterbalanced by the elastic force of the air confined within its vessels and air-cells. Whenever this external pressure exceeds the elastic force within, as in sudden descents into deep mines, a heavy and oppressive sensation is the result. If, on the contrary, a speedy rarefaction of the external air be effected, so that the elastic force of that within is more than sufficient to equal the pressure from without, as in ascending high mountains, or rising in balloons, a painful distension and even rupture of the veins and air-cells may occur.

83. The effect on the animal system of an increase of atmospheric pressure may be satisfactorily shown by means of the Strong *Glass Condensing-Chamber*, Fig. 80. This is a re-

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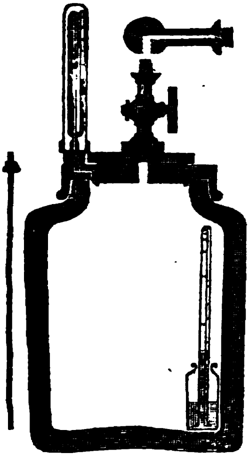
* Extreme caution is necessary against getting the least dent on the flanges of these hemispheres, as such will prevent a perfect contact of the two surfaces, and defeat the experiments. To remedy such a defect, carefully smooth down the roughness with a knife or fine file, and then grind together the flanges by the use of pumice-stone and oil, separating occasionally to prevent the formation of creases.

What pressure does the body of a common-sized man sustain? Why does not such a weight crush the body? Cause of the oppressive feeling in case of descending into deep mines? Cause of the painful sensations upon ascending to great elevations? Under ordinary circumstances how is the atmospheric pressure upon the external surface of the body counterbalanced?

ceiver of about two quarts' capacity, made of thick and well annealed glass, and covered by a firmly cemented brass cap. Into this cap screws a large plug, which may be removed to admit objects for experiment. In the centre of this plug is screwed a stop-cock for various attachments, when desired, for showing the expansive force of air, as in case of the air-gun, fire-engine, etc. A condensing-gauge, Fig. 48, for indicating the degree of pressure, is screwed upon the cap, and connects with the space within.*

Fig. 80.



Experiment.— To show the effect of an increase or diminution of atmospheric pressure on an animal. — Take two mice, or other small animals; place one in the glass *condensing-chamber*, and with the condenser force in three, four, or more atmospheres. The pressure will so compress the air-cells of the body as to *crush in* these and destroy life. Now place the other mouse under the receiver of the *air-pump*, and exhaust, when its body will become bloated by the expansion of the veins, arteries, etc., and these *will be ruptured;* thus showing that, with the present physical organization, the atmosphere near the surface of the earth is precisely adapted to the wants of the animal system.†

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* Another and cheaper form of the condensing-gauge is shown standing within the receiver. The long jet at the side is screwed to the lower end of the cock when water is used for illustrating jets, the fire-engine, etc.

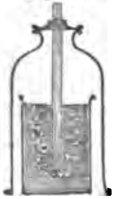
† *Experiment.*— Place in the chamber, the *rubber-bag*, Fig. 92. Inflate this, close its stop-cock, screw in the large plug, and attach the condenser.—

State the experiment showing the effect of increased atmospheric pressure on animals. The experiment showing the effect of a diminution of the same on animals.

84. *The operation of the lungs*, in inhaling and exhaling, depends on atmospheric pressure. The rise of the ribs and the fall of the diaphragm beneath, forming a partial vacuum in the chest, causes the air to flow in and expand these; and, upon the rise of the diaphragm and return of the ribs, the same is forced from the lungs, thus sustaining, by a wonderful mechanism, the process of respiration.

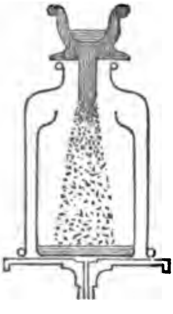
Experiment. — *To show the porosity of wood* by atmospheric pressure, insert a straight-grained cylinder tightly in a brass plate, fitted to the top of the glass receiver, and arrange in a jar of water on the pump-plate, as in Fig. 81. Cover the end of the wood cylinder with the hand, until a vacuum is formed within; then remove it, and the air will be forced rapidly through the pores of the wood, and rise through the water.

Fig. 81.



Experiment a. — Place the *Mercury-Tunnel*, Fig. 82, on the ground-top receiver, over a jar on the pump-plate, as seen in the cut. Pour mercury into the wood cup, and exhaust; the *atmospheric pressure* will force this down through the pores of the wood in a fine shower, and, should the air be dry, the friction of the mercury will excite sufficient electricity to render it luminous in the dark.*

Fig. 82.



85. *Experiment.—The atmospheric pressure upon liquids*, as in the case of their

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Force in one atmosphere, and the bag will be compressed one half. Three or four atmospheres will so compress the air within as to give the bag a shrivelled appearance. Allow the condensed air to escape, and the bag becomes inflated.

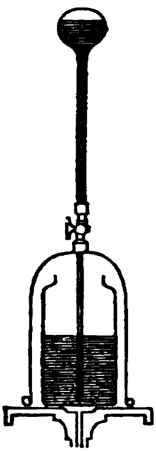
Experiment. — Place in the condensing-chamber two small *bursting-squares*, one with an open, and the other with a sealed nozzle. Condense, and the *sealed* square will be *crushed in*, while the other receives no injury.

* Guard against letting the mercury fall on the pump-plate. Keep *this* mercury-tunnel entirely free from water and other liquids.

On what principle do the lungs operate? How may the porosity of wood be shown by Fig. 81? How by the Mercury-Tunnel, Fig. 82?

rise in exhausted tubes and receivers, may be illustrated by an arrangement shown in Fig. 83. A tall glass *bolt-head*, of about one pint or quart capacity, and thirty inches length, is screwed to the cup of a bell-glass. From the lower end of the stop-cock a small tube extends to the bottom of a jar containing some colored liquid, just sufficient to fill the bolt-head. Arrange on the pump-plate, as shown in the figure, and exhaust thoroughly. The air will be drawn down from the bolt-head through the small tube, and prevented from returning again by the liquid. Now open the vent-hole, and the *atmospheric pressure* will drive up the liquid to occupy the space from which the air has been removed, leaving only a bubble in the glass bulb, and illustrating the *materiality* as well as the *pressure* of the air. To remove the bolt-head,* exhaust again, and bring the liquid below the stop-cock; then turn this and unscrew from the bell-glass.†

Fig. 83.



Experiment a.—Take a tall and straight jar, and fill to the

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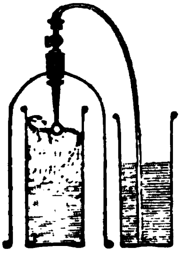
* When the bulb is filled with liquid, the pump should be worked steady, lest the glass neck be broken off by the motion. This experiment succeeds best where regard is paid to the *hydrostatic pressure* on the air escaping from the tube. A broad jar, and liquid just sufficient to allow the tube to enter when the bolt-head is filled, is preferable.

Fig. 84.

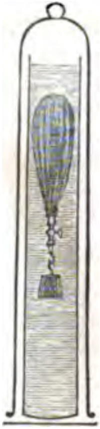


† An interesting modification of this experiment is shown by the arrangement in Fig. 84. Within the bell-glass, to the lower end of the stop-cock, is screwed a *revolving-jet*, so as to revolve in an empty jar beneath. A tube, leading from the upper end of the stop-cock, enters a jar of water. With the stop-cock closed, exhaust the bell-glass, then open; the *atmospheric pressure* will drive over the liquid through the tube and jet, causing the latter to revolve rapidly for some time, thus illustrating the cause of the rise of liquids, as well as the fact that *Barker's Mill* (see Hydrostatics) revolves equally as well in a vacuum, and independent of atmospheric reaction.

Describe the experiment with the bolt-head. What does this illustrate?

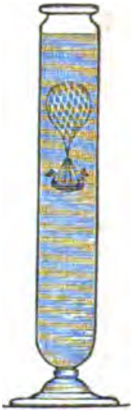
bag be not sufficiently yielding, the expansive force may be so great as to burst it. Thus, the expansive force of the air confined within shrivelled apples, raisins, etc., will cause them, when placed in an exhausted receiver, to become plump and full, and appear as when fresh.

Fig. 93.



Experiment a. — Screw into the nozzle of a small rubber bag a screw-plug, after the air has been forced from it by the hand; attach a weight, place in a tall jar of water, and cover with a bell-glass on the pump-plate, as seen in Fig. 93. Atmospheric pressure acts through the water on the air confined in the bag. Remove this pressure by exhausting, and the bag at once becomes inflated by the expansion of its confined air, and rises. Admit the air into the bell, and the bag again contracts, becomes specifically heavier than the water, and descends, thus illustrating the *Hydrostatic Balloon.*

Fig. 94.



Experiment b. — The same principle of aerial pressure and elasticity is better illustrated by the *Pneumatic Balloon,* Fig. 94. This balloon is placed in a tall jar, nearly filled with water or alcohol, with a covering of sheet-rubber tightly drawn over its top, and is partly filled with liquid, leaving a portion of air confined in the upper part, sufficient to render it a trifle lighter than the same bulk of the liquid. When floating upon the top, a pressure on the sheet-rubber will be communicated through the air to the liquid, which will be affected throughout; and, by its upward pressure, enter the small hole in the bottom of the balloon, compressing the air confined in it,

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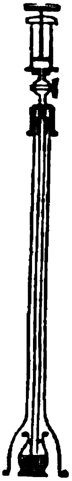
Explain the principle on which the Hydrostatic Balloon rises and sinks, as seen in Fig. 93. Explain the Pneumatic Balloon, Fig. 94.

one half times heavier than water, was seen to rise by atmospheric pressure to the height of thirty inches. By the same pressure, water will, of course, be raised thirteen and one half times as high, or to an elevation of nearly thirty-four feet. In practice, however, water will rise in an exhausted tube only about twenty-eight or thirty feet, owing to the rapid formation of a *vapory atmosphere* above the liquid when subjected to a vacuum.

Fig. 87.



87. *The absurdity of suction*, as a cause of the rise of fluids in exhausted tubes, may be clearly shown by Fig. 87. Let a glass tube be screwed to the lower end of the stop-cock of a Torricellian receiver, and extend down into a cup of mercury, as seen in the figure. To the upper end of the stop-cock screw an exhausting-syringe, and place the whole on the plate of the air-pump, and perfect a vacuum in the receiver. Now with the stop-cock open work the exhausting-syringe; the mercury *cannot be sucked up* in the barometer-tube; but admit the air into the receiver, and then work the syringe, and the mercury rises by *atmospheric pressure* on the fluid in the cup, which could not happen when this pressure was removed by an exhaustion of the receiver.*

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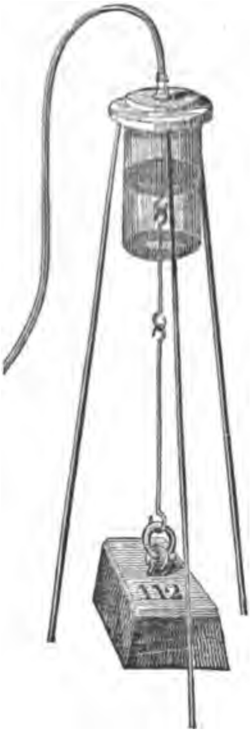
* Ignorance of pneumatic laws has occasionally produced ridiculous and expensive mistakes, as in the construction of *tight* wells, the leading of siphons over elevations *more than thirty* feet, etc. A celebrated Scotch philosopher relates that a wealthy friend had occasion to construct a pump after the most thorough manner. When completed, to the great surprise of the owner it failed to operate, and, upon inquiry, he informed his scientific friend, to whom he applied for an explanation of the cause of the failure, that he had taken great pains with the whole, having even the walls and top of the well *tightly covered* with cement. The cause of the difficulty was at once suspected, and an opening through the top for the admission of the air suggested, which proved an effectual remedy, causing at once a successful operation of the pump.

If mercury rise by atmospheric pressure to the height of thirty inches, how high may water be raised by the same pressure? Give the experiment for showing the absurdity of suction.

88. It is by atmospheric pressure that flies and other insects are enabled to walk up smooth glass, and inverted on the ceiling, and that *limpets* and *shell-fish* are held so firmly to the sides of vessels and rocks; the feet of such being formed for expelling the air, and producing a partial vacuum beneath, whereby they are held by *the force of the air* to the objects upon which they fix. This may be illustrated by

Fig. 88.



Experiment. — To the centre of a circular piece of smooth leather fasten a string. Wet the leather, and press it against the smooth surface of a pebble or piece of metal. Upon taking hold of the string a partial vacuum will be produced by the raising of the leather in its centre, and the *atmospheric pressure* will hold it to the pebble, etc., so that the body may be suspended in the air.

Air is governed by the same laws as the more dense fluids, pressing in all directions, *upwards* as well as downwards.

Experiment a.— Draw the piston to the bottom of the glass cylinder of the *upward pressure apparatus,* Fig. 88, and attach a fifty-six, or greater weight; not, however, so as to hang at all on the piston when at the bottom. Screw the hose to the pump-plate, then to the small plate on the glass cylinder, as shown in the figure. Exhaust, and the pressure of the external air will drive up the piston into the vacuum

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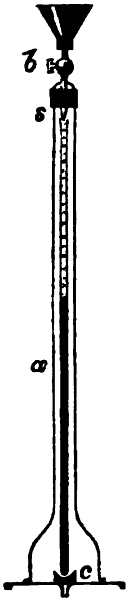
In what directions does the air exert its pressure? How may this upward pressure of the air be shown by Fig. 88?

above, taking up also the attached weight. Now pull down upon the leather strap and let go the hand; the piston and weight will rise and tilt on the air several times, forming a beautiful *atmospheric spring.*[*]

89. *The Barometer.*[†] — The weight of the atmosphere, and its power of balancing a column of a more dense fluid, pressing down with an equal weight, has been already illustrated (Fig. 86). It is on this principle that the barometer operates. Take a strong glass tube, hermetically sealed at one end and open at the other; fill this with mercury, and invert it in a cup of the same fluid, and the mercury will fall down so as to stand at about thirty inches, leaving a vacuum in the upper portion of the tube.[‡] At this height it is supported by

Fig. 89.



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[*] Observe the *order* in the above description. Guard against letting the piston come up violently against the brass plate, so as to raise it and admit the air suddenly, as in such case the weight will fall heavily upon the floor. The piston should never be taken from the cylinder by the inexperienced, as such will be apt to injure the nice edge of the leather in replacing. If the hose is stiff, guard against letting the brass plate tip off the cylinder upon the surrounding glasses.

[†] *Βαρος*, weight, and *μετρον*, a measure.

[‡] In filling these tubes heat is usually applied to expel the air which adheres to the sides of the glass, or is lodged between the particles of mercury. A more successful method of filling barometer-tubes, however, is that devised by Mr. Chamberlain, of Boston, and shown by Fig. 89. The tube is placed, with its open end up, beneath a tall receiver, *a*, provided with a funnel and stop-cock, *b*. Into this tube enters the stem, *s*, of the stop-cock. The lower and sealed end of this tube rests on a cork, *c*, so that the tube may be tilted without harm during the operation. Pour some pure mercury into the tunnel, after the apparatus is arranged on the pump-plate, and with a good air-pump exhaust thoroughly; then open the cock,

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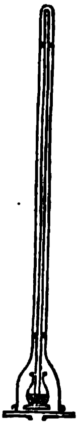
On what principle does the barometer act? Describe the manner of making a simple form of the barometer.

the atmospheric pressure. If this tube be allowed to remain in an upright position, and carefully watched, the mercurial column will be seen to vary from time to time, corresponding with the changes in the density and pressure of the air. Let now a scale, graduated and marked to indicate these changes, be affixed to the tube, and we have the common barometer.

Fig. 90.



Experiment. — The principle on which the mercurial column is supported, and rises and falls in the barometer, may be illustrated by Fig. 90. Place a common barometer-tube on the plate of the air-pump, and cover with a tall Torricellian receiver. Before exhausting, the pressure of the air on the surface of the mercury in the cistern will support this in the tube at about thirty inches.* Work the pump, and remove a portion of the air from the receiver, and the mercury falls in the tube to correspond with the rarefaction of the air, or diminution of its density and pressure. Continue to exhaust, and the mercury will rapidly descend, and soon very nearly reach a level with that in the cistern. Admit the air, and it again rises and stands as before.

90. The barometer may, therefore, be regarded as a measure

and let the mercury drip slowly into the tube until it is filled; remove the receiver, and invert and place the end of the tube in a mercury-cistern. The barometer tube is thus freed from air more effectually than by any other known method.

* Mercury is about 11,152 times heavier than air; and, since different fluids which balance each other have their heights inversely as their gravities, it follows that the height of a column of air, of uniform density, which will sustain the mercury in the barometer at 30 inches, will be $30 \times 11{,}152 = 334{,}560$ inches, or 27,880 feet = 5.28 miles. This, then, may be regarded as the average height of the atmosphere, if it be supposed of uniform density.

How may it be proved that it is the pressure of the air which supports a column of mercury in the barometer? Of what is the barometer a measure?

of the weight and density of the atmosphere; and, as these variations of density correspond somewhat to the changes of weather, this instrument is usually regarded as a *weather-glass*, and marked on the scale accordingly, *rain*, *fair*, and *dry*. Such marks are, however, arbitrary, and far from affording an infallible guide; for, while one barometer on the sea-shore, which sustains the weight of the entire atmospheric column, indicates fair weather, another, on a high eminence near by, above the lower stratum of air, and, of course, sustaining less of its weight, may, at the same time, indicate rain, or even a violent tempest. In general, however, the rise of the barometer denotes fair, and its descent stormy weather. A sudden and remarkable fall of the mercury usually precedes and attends violent winds; hence this instrument is of the highest service to mariners when sailing in tropical latitudes, where they are liable to meet with whirlwinds, typhoons, and other fearful winds; the barometer often giving sufficient warning to enable them to avert these dangers.

The barometer is also of great value in *determining heights*. The density of the air diminishes regularly as we ascend from the level of the ocean; thus, at three miles it is only about one half; at seven miles, one fourth, and so on. Now, as the height of the mercury corresponds to the density of the air, and this to the elevation, the height of any place may be readily known by noting the point at which the mercury stands at that place. Thus, when ascending a hill or mountain, or rising in a balloon, the elevation may be known at any time by consulting the barometer. If this, for instance, stand at 24.79 inches, the

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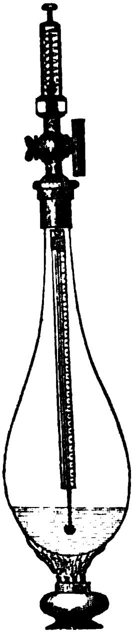
Why do the rise and fall of the mercury in this usually indicate changes of weather? How is the scale of the barometer usually marked? What is said of these marks? Why are they not unerring guides in determining the states of weather? In general, what does the rise of the mercury indicate? What its fall? What does a sudden fall of the mercury indicate? Where is the barometer of special service? How are we enabled to determine heights by means of the barometer?

elevation is nearly 5,000 feet; if at fifteen inches 10,000 feet; and so diminishing with the elevation.

91. *The Boiling of Liquids.* — The temperature at which liquids boil varies with the pressure on these. Thus, under the ordinary atmospheric pressure of fifteen pounds to the square inch, water boils at 212° Fahrenheit. If, now, the same be placed in a receiver, and a partial vacuum effected by means of the air-pump, the degree of heat required for making it boil will become less; and in the vacuum produced by a superior modern air-pump the liquid will boil *even at the freezing-point* of water. On the contrary, water may be heated, under a pressure, *so hot as to melt lead*, and yet not boil.

Fig. 91.



Experiment. — Take a strong glass flask provided with a stop-cock, as seen in Fig. 91; place in this a thermometer prepared for the purpose. Pour in some water, and, with the stop-cock open, apply heat. When the thermometer indicates 212°, the elasticity of the vapor will overcome the atmospheric pressure, and ebullition will begin. Close the stop-cock so as to prevent the escape of the vapor; . a greater pressure will at once stop the boiling, and, if the heat be continued, the thermometer will rise several degrees before this will commence again. Now remove the lamp, and allow the liquid to cool considerably below 212°, and, with the stop-cock closed, plunge the flask in *cold water*, when a rapid boiling will be renewed, owing to the formation of a partial vacuum by the condensation of the vapor above the

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How does the temperature at which liquids boil vary? The boiling-point under the ordinary pressure of the atmosphere? What is said of the boiling-point in an exhausted receiver? Describe the process of boiling in the glass flask, Fig. 91. Why does the liquid again boil when the flask is plunged in cold water?

water in the flask. This *boiling by cooling* may be repeated several times, and constitutes the *culinary paradox.** From the same cause liquids boil at a much lower heat on mountains than near the level of the ocean. Thus, on the summit of Mont Blanc, the boiling-point of water is only 180°, a temperature too low for cooking many common vegetables.

Upon this same principle, Mr. Howard, of England, a few years since, devised a plan for boiling down syrups at a low temperature, by placing these in large *vacuum-pans*, from which the air and vapor may be constantly removed by air-pumps. By this arrangement much less heat is required, and the quality of the sugars thereby greatly improved.

Experiment a. — *Water at different temperatures boils at different degrees of rarefaction.* — Fill the tall jar, Fig. 85, about half full of *cold* water, then pour in carefully, through a long tunnel, a pint of *hot* water. Cover with the bell-glass, and exhaust, and the warm water will boil violently, while no visible effect will be produced on the cold water below.

92. *The Atmospheric Telegraph*, an invention recently patented by Mr. I. S. Richardson, is designed for transmitting mails and other matter, at great speed, through exhausted tubes, by the force of *atmospheric pressure.* A piston or plunger, packed with soft leather, fits the tube; to this is attached a long cylindrical mail-bag. When ready for transmission, the plunger with its attachments is placed in the end of the tube behind an air-tight "cut-off." The tube is then exhausted by large air-pumps, to be worked by steam

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* A spring gauge, for showing the degree of the pressure of the vapor, is screwed to the cock, as seen in the figure. This may be removed.

What is said of the boiling-point of liquids on mountains? The boiling-point on Mont Blanc? The use and advantages of vacuum-pans? Give Experiment *a*. What is the design of the Atmospheric Telegraph? How is it operated?

power; and when a tolerable vacuum is effected, the "cut-off" is raised, and the plunger set free on the side of the vacuum. Atmospheric pressure then forces this into and through the exhausted tube "with a speed equal to about six hundred and thirty-five miles per hour." Although highly operative on a small plan, as shown by models, yet the practicability of the Atmospheric Telegraph on a large scale remains to be tested.

FLUIDITY OF AIR.

93. Air is a fluid, and follows the general laws which govern the flow and equilibrium of water and the more dense fluids. Thus, when a space is rendered partially void — as the receiver of an air-pump, for instance — by exhaustion, the fluid air around, when permitted, at once flows in to fill the empty space. So, on a more extended scale, the rarefaction of the air over a certain region by the sun's heat, causes the surrounding denser portions to flow in, forming the gentle zephyr as well as the terrific tornado.

Again; air, like the more dense fluids, raises and floats bodies specifically lighter than itself. Thus, as water raises and floats wood, cork, etc., so air raises and buoys up a balloon inflated with hydrogen, which is specifically lighter than itself. In the same way clouds and smoke are lifted and sustained by the air.

ELASTICITY AND EXPANSION OF AIR.

94. Of elastic fluids air may be taken as a type or example, being permanently elastic. If a portion of this be subjected to the most intense pressure for years, it loses none of its elasticity, but at once resumes its original volume when this pressure is removed.

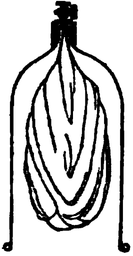
The speed at which it is proposed to transmit packages by this? Is air a fluid? Give any illustrations of this. Of what class of fluids may air be taken as the type? What is said of its elasticity?

As we have already remarked (90), the density of the atmosphere diminishes as we ascend from the earth, where the pressure of the incumbent mass becomes less and less. This is agreeable with the *law of Mariotte*, that "*The volumes of gases are in the inverse ratio of the pressures which they support.*"

Experiment.—Take the *siphon-barometer*, Fig. 86, remove the hose, and, with the stop-cock open, pour in mercury through the long arm until it shall stand just above the curve in either arm. Close the stop-cock; the air in the short arm now sustains the ordinary pressure of a single atmosphere. Pour mercury into the long arm until it shall stand at the same height above that in the short arm as that in the barometer. The air confined in the short arm now sustains a weight equal to *two* atmospheres, and has diminished in bulk *one half*. The weight of an additional atmosphere would cause it to occupy one third its original volume, and so with the pressure of each additional atmosphere will be a proportional diminution of volume, agreeably with the above law.

95. *The expansion of air has no assignable limits*, but, as the pressure is removed, the want of cohesion between its particles causes them to separate, and the fluid to occupy an indefinite volume.

Fig. 92.



Experiment— After pressing the air as far as possible from the *sheet-rubber bag*, screw into the nozzle a hook-plug, to make it air-tight, and suspend it under a bell-glass from the stop-cock, as seen in Fig. 92, or, which is better, from a sliding-rod. Place the whole on the pump-plate, and exhaust; the rarefaction in the receiver will cause the trifle of air remaining in the bag to *expand and swell it to plumpness*; and, if the

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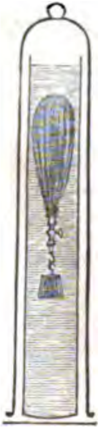
What is the law of Mariotte? How may this be illustrated by the siphon-barometer, Fig. 86? What is said of the expansion of the air? Show the expansive force of air by the arrangement, Fig. 92.

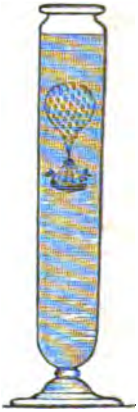
bag be not sufficiently yielding, the expansive force may be so great as to burst it. Thus, the expansive force of the air confined within shrivelled apples, raisins, etc., will cause them, when placed in an exhausted receiver, to become plump and full, and appear as when fresh.

Fig. 93.



Experiment a. — Screw into the nozzle of a small rubber bag a screw-plug, after the air has been forced from it by the hand; attach a weight, place in a tall jar of water, and cover with a bell-glass on the pump-plate, as seen in Fig. 93. Atmospheric pressure acts through the water on the air confined in the bag. Remove this pressure by exhausting, and the bag at once becomes inflated by the expansion of its confined air, and rises. Admit the air into the bell, and the bag again contracts, becomes specifically heavier than the water, and descends, thus illustrating the *Hydrostatic Balloon*.

Fig. 94.



Experiment b. — The same principle of aerial pressure and elasticity is better illustrated by the *Pneumatic Balloon*, Fig. 94. This balloon is placed in a tall jar, nearly filled with water or alcohol, with a covering of sheet-rubber tightly drawn over its top, and is partly filled with liquid, leaving a portion of air confined in the upper part, sufficient to render it a trifle lighter than the same bulk of the liquid. When floating upon the top, a pressure on the sheet-rubber will be communicated through the air to the liquid, which will be affected throughout; and, by its upward pressure, enter the small hole in the bottom of the balloon, compressing the air confined in it,

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Explain the principle on which the Hydrostatic Balloon rises and sinks, as seen in Fig. 93. Explain the Pneumatic Balloon, Fig. 94.

[illegible]

Experiment.—[illegible]

95. [illegible]

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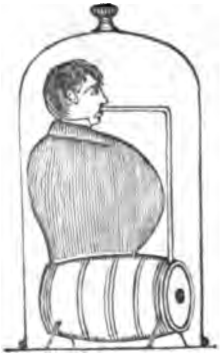
nearly full of water, and place in it a fish; remove the condensing-gauge, and in its place screw a plug; connect with the *air-pump* by means of a hose and coupler, and exhaust. The removal of the pressure from the water, and through this from the air-bladder, will cause this to expand, and bring the fish to the top of the water; and, if the rarefaction be carried sufficiently far, the bladder will be ruptured. Again, attach the *condenser*, and work it a few strokes, and the compression of the air in the bladder will bring the fish to the bottom, in spite of its efforts to rise.

96. *Experiment.*—*Bacchus in Vacuo*, Fig. 96, is an amusing illustration of the expansion of air. This is an image mounted on a small barrel, which has a partition in the middle dividing it in two parts, one of which is open to atmospheric pressure, while the other is closed, and contains some colored liquid, with a small portion of confined air above it. From the end of the barrel in which the liquid is, a glass tube passes into the mouth of the image, and down through it to the open end of the barrel. Upon covering with a bell-glass, and exhausting, *the expansion of the air in the closed end of the barrel* forces the liquid up the glass into the mouth of the image, while, at the same time, a tight rubber bag concealed under the dress, expands and swells the abdomen, thus adding to the illusion.

Fig. 96.



Experiment a.—The elastic force of air acting on liquids is shown by the *Fountain in Vacuo*, Fig. 97. Fill the lower globe nearly full of colored water, and let the centre and open-

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In the experiment of Bacchus in Vacuo, what causes the liquid to rise in the tube leading from the barrel to the mouth? Cause of the expansion of the bag attached to the image? What causes the liquid to flow from the lower to the upper globe, in Fig. 97?

and causing the balloon to sink, from an increase of its specific gravity. Remove the pressure, and the balloon rises.*

Remarks. — This instrument illustrates several important principles in pneumatics and hydrostatics. By the *materiality of the air*, which intervenes, pressure is communicated to the water; the *compressibility of the air* in the balloon causes it to sink; its *elasticity* expels the water again from this, causing it to rise, while the *lightness of the air* buoys up the balloon. The *pressure of liquids is in all directions*, for the water rises in the balloon, while the pressure on it is downward, and their *pressure is as the depth*, for the air is diminished in bulk as the balloon descends.

On the principles illustrated by the last experiment, *fishes rise and sink in water*. These are provided with an air-bladder, lying along the vertebral column, by a voluntary contraction and expansion of which, they are enabled to change their specific gravity, so as to descend or rise at pleasure.

Experiment c. — Fill the condensing-chamber, Fig. 80,

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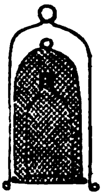
* The pressure required to sink this will diminish as the depth of its descent increases, and when nicely balanced at the top, and forced to the bottom, it will remain there, from the pressure of the water above on the air confined within the balloon. To raise it again, place the jar under a tall bell-glass, Fig. 91, and exhaust a trifle; or take a long slim tube, with a curved end, pass it down into the jar, and bring to the small hole in the bottom of the balloon; then apply the mouth to the tube, and blow in air until the balloon rises.

Fig. 95.



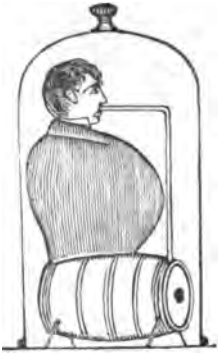
The expansive force of air may be shown by screwing into the hole of the pump-plate the guard-plug, Fig. 54, and placing on the plate, beneath a wire-guard, a *bursting-square*, Fig. 95, the nozzle of which has been closed with sealing-wax. Cover with a bell-glass, and exhaust. The removal of the external pressure will cause the air confined within to exert its expansive force without a counterbalance, and the glass will burst, flying into a thousand pieces. Observe the caution in § 80.

What important principles are illustrated by this experiment? Cause of the rise and fall of fishes in water? Illustration with the condensing-chamber?

nearly full of water, and place in it a fish; remove the condensing-gauge, and in its place screw a plug; connect with the *air-pump* by means of a hose and coupler, and exhaust. The removal of the pressure from the water, and through this from the air-bladder, will cause this to expand, and bring the fish to the top of the water; and, if the rarefaction be carried sufficiently far, the bladder will be ruptured. Again, attach the *condenser*, and work it a few strokes, and the compression of the air in the bladder will bring the fish to the bottom, in spite of its efforts to rise.

96. *Experiment.*—*Bacchus in Vacuo*, Fig. 96, is an amusing illustration of the expansion of air. This is an image mounted on a small barrel, which has a partition in the middle dividing it in two parts, one of which is open to atmospheric pressure, while the other is closed, and contains some colored liquid, with a small portion of confined air above it. From the end of the barrel in which the liquid is, a glass tube passes into the mouth of the image, and down through it to the open end of the barrel. Upon covering with a bell-glass, and exhausting, *the expansion of the air in the closed end of the barrel* forces the liquid up the glass into the mouth of the image, while, at the same time, a tight rubber bag concealed under the dress, expands and swells the abdomen, thus adding to the illusion.

Fig. 96.



Experiment a.—The elastic force of air acting on liquids is shown by the *Fountain in Vacuo*, Fig. 97. Fill the lower globe nearly full of colored water, and let the centre and open-

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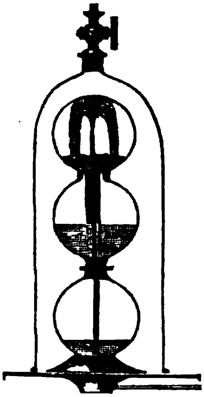
In the experiment of Bacchus in Vacuo, what causes the liquid to rise in the tube leading from the barrel to the mouth? Cause of the expansion of the bag attached to the image? What causes the liquid to flow from the lower to the upper globe, in Fig. 97?

mouthed globe with its jets be screwed into this, while the upper, with its neck down, covers the jet in the centre globe. Place on the pump-plate, and cover with a bell-glass; exhaust, and remove the pressure of the air from the open jet. *The expansive force of the air* in the lower globe will drive the water into the upper, from which it falls into the centre globe. Now admit the air, and the water is all driven up, and remains in the upper globe. Exhaust, and it again falls into the centre one.*.

Fig. 97.



97. *The expansive force of the air is directly as the pressure upon it.*— Remove the exterior jet of the *Artificial Fountain-glass*, Fig 99. Screw to the centre hole of the pump-plate, and exhaust; replace the jet, immerse the end in water, and open the stop-cock. The pressure of the external air will force in the water through the long inner jet, forming a beautiful vacuum fountain. When about two thirds filled, attach the

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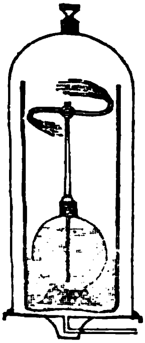
Fig. 98.



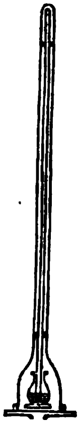
* A *revolving-jet and fountain in vacuo*, beautifully illustrates the same property of air acting on liquids. Attach a revolving-jet to the lower globe in the last experiment, and arrange on pump-plate, as seen in Fig. 98. Exhaust, and the expansive force of the small body of air confined above the water will act on this, and force it up through the jet, causing this to revolve rapidly, independent of atmospheric reäction.

Keep these revolving-jets well oiled, and regulate their freedom by the binding-screw at the end. After such experiments, requiring the use of water, brass-work should never be set away in a damp and neglected state. More apparatus is injured by carelessness and neglect, than by use.

Why, upon admitting the air again into the receiver, does the liquid flow from the middle into the upper globe? What is the expansive force of air as? Give the experiments with the Artificial Fountain-glass.

the atmospheric pressure. If this tube be allowed to remain in an upright position, and carefully watched, the mercurial column will be seen to vary from time to time, corresponding with the changes in the density and pressure of the air. Let now a scale, graduated and marked to indicate these changes, be affixed to the tube, and we have the common barometer.

Fig. 90.



Experiment. — The principle on which the mercurial column is supported, and rises and falls in the barometer, may be illustrated by Fig. 90. Place a common barometer-tube on the plate of the air-pump, and cover with a tall Torricellian receiver. Before exhausting, the pressure of the air on the surface of the mercury in the cistern will support this in the tube at about thirty inches.* Work the pump, and remove a portion of the air from the receiver, and the mercury falls in the tube to correspond with the rarefaction of the air, or diminution of its density and pressure. Continue to exhaust, and the mercury will rapidly descend, and soon very nearly reach a level with that in the cistern. Admit the air, and it again rises and stands as before.

90. The barometer may, therefore, be regarded as a measure

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and let the mercury drip slowly into the tube until it is filled; remove the receiver, and invert and place the end of the tube in a mercury-cistern. The barometer tube is thus freed from air more effectually than by any other known method.

* Mercury is about 11,152 times heavier than air; and, since different fluids which balance each other have their heights inversely as their gravities, it follows that the height of a column of air, of uniform density, which will sustain the mercury in the barometer at 30 inches, will be 30 × 11,152 = 334,560 inches, or 27,880 feet = 5.28 miles. This, then, may be regarded as the average height of the atmosphere, if it be supposed of uniform density.

How may it be proved that it is the pressure of the air which supports a column of mercury in the barometer? Of what is the barometer a measure?

of the weight and density of the atmosphere; and, as these variations of density correspond somewhat to the changes of weather, this instrument is usually regarded as a *weather-glass*, and marked on the scale accordingly, *rain*, *fair*, and *dry*. Such marks are, however, arbitrary, and far from affording an infallible guide; for, while one barometer on the sea-shore, which sustains the weight of the entire atmospheric column, indicates fair weather, another, on a high eminence near by, above the lower stratum of air, and, of course, sustaining less of its weight, may, at the same time, indicate rain, or even a violent tempest. In general, however, the rise of the barometer denotes fair, and its descent stormy weather. A sudden and remarkable fall of the mercury usually precedes and attends violent winds; hence this instrument is of the highest service to mariners when sailing in tropical latitudes, where they are liable to meet with whirlwinds, typhoons, and other fearful winds; the barometer often giving sufficient warning to enable them to avert these dangers.

The barometer is also of great value in *determining heights.* The density of the air diminishes regularly as we ascend from the level of the ocean; thus, at three miles it is only about one half; at seven miles, one fourth, and so on. Now, as the height of the mercury corresponds to the density of the air, and this to the elevation, the height of any place may be readily known by noting the point at which the mercury stands at that place. Thus, when ascending a hill or mountain, or rising in a balloon, the elevation may be known at any time by consulting the barometer. If this, for instance, stand at 24.79 inches, the

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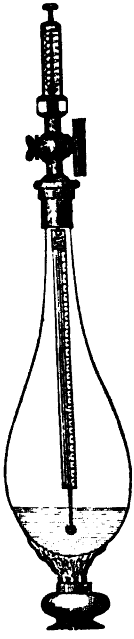
Why do the rise and fall of the mercury in this usually indicate changes of weather? How is the scale of the barometer usually marked? What is said of these marks? Why are they not unerring guides in determining the states of weather? In general, what does the rise of the mercury indicate? What its fall? What does a sudden fall of the mercury indicate? Where is the barometer of special service? How are we enabled to determine heights by means of the barometer?

elevation is nearly 5,000 feet; if at fifteen inches 10,000 feet; and so diminishing with the elevation.

91. *The Boiling of Liquids.* — The temperature at which liquids boil varies with the pressure on these. Thus, under the ordinary atmospheric pressure of fifteen pounds to the square inch, water boils at 212° Fahrenheit. If, now, the same be placed in a receiver, and a partial vacuum effected by means of the air-pump, the degree of heat required for making it boil will become less; and in the vacuum produced by a superior modern air-pump the liquid will boil *even at the freezing-point* of water. On the contrary, water may be heated, under a pressure, *so hot as to melt lead*, and yet not boil.

Fig. 91.



Experiment. — Take a strong glass flask provided with a stop-cock, as seen in Fig. 91; place in this a thermometer prepared for the purpose. Pour in some water, and, with the stop-cock open, apply heat. When the thermometer indicates 212°, the elasticity of the vapor will overcome the atmospheric pressure, and ebullition will begin. Close the stop-cock so as to prevent the escape of the vapor; a greater pressure will at once stop the boiling, and, if the heat be continued, the thermometer will rise several degrees before this will commence again. Now remove the lamp, and allow the liquid to cool considerably below 212°, and, with the stop-cock closed, plunge the flask in *cold water*, when a rapid boiling will be renewed, owing to the formation of a partial vacuum by the condensation of the vapor above the

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How does the temperature at which liquids boil vary? The boiling-point under the ordinary pressure of the atmosphere? What is said of the boiling-point in an exhausted receiver? Describe the process of boiling in the glass flask, Fig. 91. Why does the liquid again boil when the flask is plunged in cold water?

water in the flask. This *boiling by cooling* may be repeated several times, and constitutes the *culinary paradox.** From the same cause liquids boil at a much lower heat on mountains than near the level of the ocean. Thus, on the summit of Mont Blanc, the boiling-point of water is only 180°, a temperature too low for cooking many common vegetables.

Upon this same principle, Mr. Howard, of England, a few years since, devised a plan for boiling down syrups at a low temperature, by placing these in large *vacuum-pans*, from which the air and vapor may be constantly removed by air-pumps. By this arrangement much less heat is required, and the quality of the sugars thereby greatly improved.

Experiment a.— Water at different temperatures boils at different degrees of rarefaction.— Fill the tall jar, Fig. 85, about half full of *cold* water, then pour in carefully, through a long tunnel, a pint of *hot* water. Cover with the bell-glass, and exhaust, and the warm water will boil violently, while no visible effect will be produced on the cold water below.

92. *The Atmospheric Telegraph*, an invention recently patented by Mr. I. S. Richardson, is designed for transmitting mails and other matter, at great speed, through exhausted tubes, by the force of *atmospheric pressure.* A piston or plunger, packed with soft leather, fits the tube; to this is attached a long cylindrical mail-bag. When ready for transmission, the plunger with its attachments is placed in the end of the tube behind an air-tight "cut-off." The tube is then exhausted by large air-pumps, to be worked by steam

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* A spring gauge, for showing the degree of the pressure of the vapor, is screwed to the cock, as seen in the figure. This may be removed.

What is said of the boiling-point of liquids on mountains? The boiling-point on Mont Blanc? The use and advantages of vacuum-pans? Give Experiment *a*. What is the design of the Atmospheric Telegraph? How is it operated?

power; and when a tolerable vacuum is effected, the "cut-off" is raised, and the plunger set free on the side of the vacuum. Atmospheric pressure then forces this into and through the exhausted tube "with a speed equal to about six hundred and thirty-five miles per hour." Although highly operative on a small plan, as shown by models, yet the practicability of the Atmospheric Telegraph on a large scale remains to be tested.

FLUIDITY OF AIR.

93. Air is a fluid, and follows the general laws which govern the flow and equilibrium of water and the more dense fluids. Thus, when a space is rendered partially void — as the receiver of an air-pump, for instance — by exhaustion, the fluid air around, when permitted, at once flows in to fill the empty space. So, on a more extended scale, the rarefaction of the air over a certain region by the sun's heat, causes the surrounding denser portions to flow in, forming the gentle zephyr as well as the terrific tornado.

Again; air, like the more dense fluids, raises and floats bodies specifically lighter than itself. Thus, as water raises and floats wood, cork, etc., so air raises and buoys up a balloon inflated with hydrogen, which is specifically lighter than itself. In the same way clouds and smoke are lifted and sustained by the air.

ELASTICITY AND EXPANSION OF AIR.

94. Of elastic fluids air may be taken as a type or example, being permanently elastic. If a portion of this be subjected to the most intense pressure for years, it loses none of its elasticity, but at once resumes its original volume when this pressure is removed.

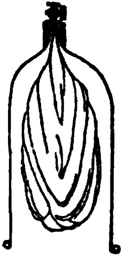
The speed at which it is proposed to transmit packages by this? Is air a fluid? Give any illustrations of this. Of what class of fluids may air be taken as the type? What is said of its elasticity?

As we have already remarked (90), the density of the atmosphere diminishes as we ascend from the earth, where the pressure of the incumbent mass becomes less and less. This is agreeable with the *law of Mariotte*, that "*The volumes of gases are in the inverse ratio of the pressures which they support.*"

Experiment.—Take the *siphon-barometer*, Fig. 86, remove the hose, and, with the stop-cock open, pour in mercury through the long arm until it shall stand just above the curve in either arm. Close the stop-cock; the air in the short arm now sustains the ordinary pressure of a single atmosphere. Pour mercury into the long arm until it shall stand at the same height above that in the short arm as that in the barometer. The air confined in the short arm now sustains a weight equal to *two* atmospheres, and has diminished in bulk *one half*. The weight of an additional atmosphere would cause it to occupy one third its original volume, and so with the pressure of each additional atmosphere will be a proportional diminution of volume, agreeably with the above law.

95. *The expansion of air has no assignable limits*, but, as the pressure is removed, the want of cohesion between its particles causes them to separate, and the fluid to occupy an indefinite volume.

Fig. 92.



Experiment— After pressing the air as far as possible from the *sheet-rubber bag*, screw into the nozzle a hook-plug, to make it air-tight, and suspend it under a bell-glass from the stop-cock, as seen in Fig. 92, or, which is better, from a sliding-rod. Place the whole on the pump-plate, and exhaust; the rarefaction in the receiver will cause the trifle of air remaining in the bag to *expand and swell it to plumpness*; and, if the

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What is the law of Mariotte? How may this be illustrated by the siphon-barometer, Fig. 86? What is said of the expansion of the air? Show the expansive force of air by the arrangement, Fig. 92.

THE MECHANICAL AGENCIES OF STEAM.

103. Water, when heated to a temperature of 212°, under the ordinary pressure of the atmosphere, is resolved into an invisible vapor, which, upon condensation by cold, becomes visible, and is known as steam. By such a change, in passing from a liquid to a vapor, the volume of the water is vastly increased, occupying a space about *seventeen hundred* times greater in the latter than in the former state. Such an increase of volume gives to steam great power as a motive agent, which, through the steam-engine, has been applied of late years to propelling every variety of machinery. It is the province of chemistry to explain the laws of heat which regulate the formation of vapor or steam, and of natural philosophy to show the application of this as a mechanical force.

The elastic force of vapor, from water at 212°, is just sufficient to overcome the pressure of the atmosphere, and at such a temperature in the open air ebullition accordingly goes on freely; but, if water be confined in a tight vessel, its boiling-point will be raised (§ 92), and the density and elastic force of its vapor will increase with its temperature. This may be illustrated by an apparatus known as *Marcet's Steam-Globe*, Fig. 112.

Experiment. — Unscrew from the brass globe the long hermetically sealed glass tube, with its graduated scale, 5, and through the opening pour in sufficient mercury, 7, to fill the bore of the tube, and then cover with water, 8, in the proportions shown in the cut; replace the tube and scale. With the thermometer, 4, screwed into the side, and the stop-cock, 6, open, apply heat. At 212° the water will boil. Now

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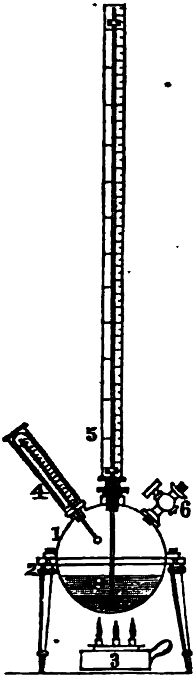
What is steam? What is said of the volume of water in passing from a liquid to a vapor state? What gives to steam its great motive power? What is said of the elastic force of vapor from water at 212° of Fahrenheit's thermometer? Effect upon the boiling-point by heating water in a tight vessel? Give the experiment with Marcet's Steam-Globe. Does the elastic force of the vapor increase with its temperature?

close the stop-cock, and the boiling ceases, while the temperature and elastic force of the steam increase. This, pressing on the water and mercury, will force the latter up the tube, at heights varying with the tension and pressure of the steam.* Thus, at a temperature of 249°, the pressure of the vapor will have increased to that of two atmospheres, 293° to four; 320° to six atmospheres, and so on. Thus, the elastic force corresponding to each additional degree of heat may be shown by this arrangement up to that of twelve or sixteen atmospheres. This force of vapor will be found, moreover, to increase in a far more rapid ratio than the temperature; that is to say, a definite elevation of temperature produces a far greater increase of tension in the vapor at high, than at low temperatures. Thus, from 212° to 249° (an elevation of 37°), the expansive force of the steam is increased only a single atmosphere; while from 438° to 456° (a rise of only 18°), shows an additional increase in the elastic force of the vapor, equal to *five* atmospheres.†

Fig. 112.



104. *Experiment.* — The elastic force of steam may be again illustrated by the *Eolopile*, Fig. 113. This is a hollow brass bulb, provided with a handle and jet. Heat the bulb over a spirit-lamp, and then plunge the jet and bulb in cold water; the water will be driven

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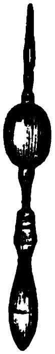
* This tube has its upper end hermetically sealed, and the degree of pressure is shown as with the Condensing-Guage, Fig. 48.

† When this steam-globe is charged to a pressure of seven, eight, or more atmospheres, attach to the stop-cock the *air-gun*, *revolving-jet*, etc., and the same experiments may be performed by the elastic force of steam as by air, except that those by steam will be with far more energy.

Explain the experiment with the Eolopile, Fig. 113.

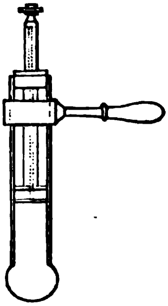
into the bulb to supply the partial vacuum occasioned by the expulsion of the air when heated. When this is partly filled, hold it again in the flame. Steam will soon form from the water, and by its elastic force be driven forcibly through the jet.*

Fig. 113.



The Steam-Engine. — This may be justly regarded as the most valuable invention of modern times, since none have contributed more to the physical comforts and social delights of man. The present form of the steam-engine is due mainly to the genius and mechanical skill of Sir James Watt, of England, whose investigations on this subject commenced about the year 1763. The power of steam, as a propelling agent, was known for some time previous to this date, and applied through that form of engine now known as the *Atmospheric-Engine.* This was an exceedingly rude and expensive application of steam, and it was from observing its defects that Mr. Watt was led to conceive the present form of the steam-engine.

Fig. 114.



In order to appreciate the discovery of Watt, it is necessary to gain some idea of the operation of the

105. *Atmospheric-Engine.* — This may be illustrated by an apparatus shown in Fig. 114. To a straight brass cylinder is fitted a piston, with its rod moving through a hole in the screw-cap. To this cylinder is attached a wooden handle for holding, while heating, and

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* In place of the straight, attach the revolving jet, and this will be driven rapidly by the escaping steam. A steam-cannon, for firing balls in rapid succession, and to a great distance, has been devised.

What is said in regard to the Steam-Engine? To whom are we chiefly indebted for this invention? By what form of engine was the power of steam first applied? What is said of this engine? Describe the Atmospheric-Engine?

just above this, on the side of the cylinder, is a small spring safety valve, and to the bottom of the same is soldered a copper globe for containing the water.

Experiment.—Remove the screw-cap and pour in some water, or, which is better, alcohol; replace, and hold the globe in the flame of a spirit-lamp; steam will soon form, and by its expansive force drive up the piston; then plunge the bulb in cold water. A vacuum will be suddenly formed by the condensation of the steam, and *atmospheric pressure* will force the piston to the bottom. Hold again in the flame, and then in the cold water, and again the piston will be driven up and down; and so the process may be continued. If, now, the end of the piston-rod be attached to a wheel-crank or lever, the rise and fall of the piston will give motion to these, and afford a general illustration of the atmospheric-engine.

Thus, it will be perceived, that, at every descent of the piston, the cylinder must be cooled, in order to condense the steam, and form the required vacuum. This was done by injecting into the cylinder a stream of cold water, which rendered a great expenditure of heat necessary to bring the water and cylinder again to the boiling-point of water. To remedy this, Watt conceived the idea of a *separate condensation,* whereby a vacuum might be formed without at the same time cooling the cylinder Accordingly, by a valve placed in the bottom of the cylinder, the steam was allowed to escape through a pipe into a separate chamber, where, by an injection of cold water, it was immediately condensed, and a vacuum thus formed in the cylinder.

106. Again, *the cooling of the cylinder*, by the entry of the air as the piston descended, was a second defect which engaged the attention of Watt. To remedy this he devised the plan of a *close* cylinder, employing *steam* instead of the atmosphere to force down the piston, thus keeping the cylinder continually heated by the steam, and so preventing the condensation of the

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Explain its operation by the figure. What plan did Watt conceive in order to avoid the cooling of the cylinder?

same. A third difficulty now remained to be overcome, which was the removal of the air and warm water from the condenser. To effect this, he contrived to attach to the condenser a pump with a tube leading to the bottom of the chamber, and worked by steam, whereby these might be constantly pumped out.

In addition to these important discoveries, was the providing a wood or metallic covering for the cylinder, whereby the escape of the heat and condensation of the steam was further prevented. This covering is known as the *jacket*. With these improvements an actual saving of *three fourths* of the fuel required for the atmospheric-engine was effected. With these preliminary remarks, the learner is now prepared to understand the different parts, as shown in the

107. *Section Model of Watt's Improved Steam-Engine*, Fig. 115.—The cylinder, C, is made air-tight, so that the atmospheric air can exert no force on the piston moving in it. The steam from the boiler is conducted through the *steam-pipe*, and enters the cylinder alternately at A and B, being admitted through the slide-valves attached to the rod, D, which open and close these apertures at proper intervals, by means of an attachment connecting with the eccentric, E, of the fly-wheel, F. From the steam-box leads the *exhaust-pipe*, which enters the *water-cistern* or condenser, into which the steam, after performing its office in the cylinder, is conducted. Attached to this condenser is the air-pump, P, which is worked by a connection with the beam. A parallel work, H, connects the pump and piston-rods, and serves to keep these perpendicular and parallel during their ascent and descent. The beam-lever, which connects at one end with the piston-rod, is attached, and gives a crank motion to the fly-wheel, F (§ 37), at the other. In order to prevent irregu-

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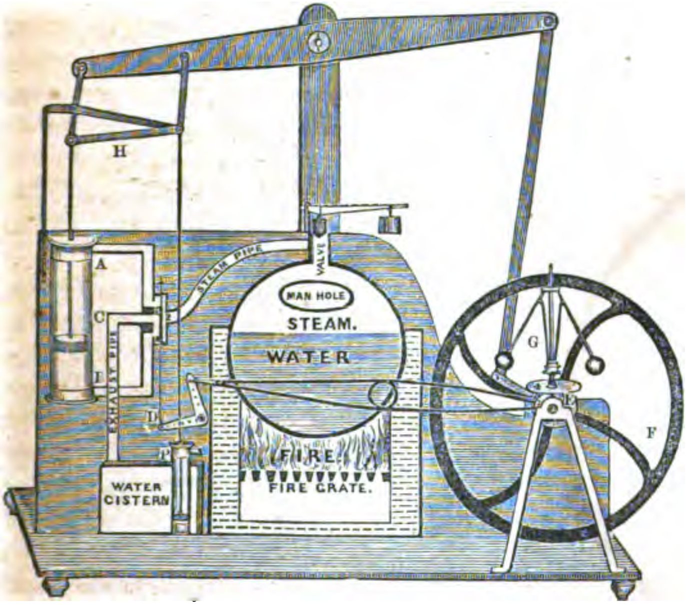
How did he remedy the cooling of the cylinder by the entry of cold air as the piston descended? What was Watt's third improvement in reference to the steam-engine? What amount of fuel was saved by these improvements? Point out the parts, and explain the operation of Watt's engine, by the section model, Fig. 115.

larities in the force of the steam, and of course in the motion of the machinery driven, the governor, G (§ 38), is employed.*

Fig. 115.



Upon the boiler is placed a steam-valve for the escape of the steam when the boiler is overcharged, the pressure of which is regulated by the lever and weight.

Owing to the *accelerated* motion given to the piston by the full force of the steam acting during its whole passage through the cylinder, it was found necessary in some way to regulate

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* The full construction of this regulator is not shown in the cut, and can only be comprehended by a working model.

What remedy was devised in order to avoid the injury from the accelerated motion acquired by the piston?

this force. In order to do this, the valves attached to D (Fig. 115) were so contrived as to close and cut off the steam when the piston had made about one third of its descent, allowing this to drive the piston through the remaining two thirds, by its expansive force alone. Thus, a uniform velocity was given to the piston during its entire passage, besides effecting a great economy in the expenditure of the steam.

If the water-cistern or condenser, shown in Fig. 115, be dispensed with, and the steam allowed to escape from the cylinder directly into the atmosphere, instead of passing into a vacuum, the piston will be resisted by the pressure of the atmosphere; and of course, to obtain the same power for the engine as before, an additional tension of steam will be required equal to this pressure. Hence, owing to this additional force required, such are termed *high-pressure* engines.

By dispensing with the condenser, air-pump, etc., the high-pressure engine of the same power is much smaller, lighter, and cheaper. These are consequently much used in smaller steam-boats, and for locomotion on rail-roads.

108. *An Operative Model of the High-Pressure Horizontal Cylinder Engine*, is shown by Fig. 116. From what has been already said, the various parts of this engine may be readily understood by reference to the figure.

B is the boiler; C, the cylinder; D, the steam-box, where the steam is admitted through the slide-valves to the cylinder; E, the lever which opens the valve admitting the steam to the steam-box; F, the piston-rod, attached to the slide, R, which moves upon two parallel rods, and so guides the piston-rod in its motions to and fro. This corresponds to the parallel work of Watt's engine. G, the driving-rod, attached to the crank of the shaft, on which are fixed the balance-

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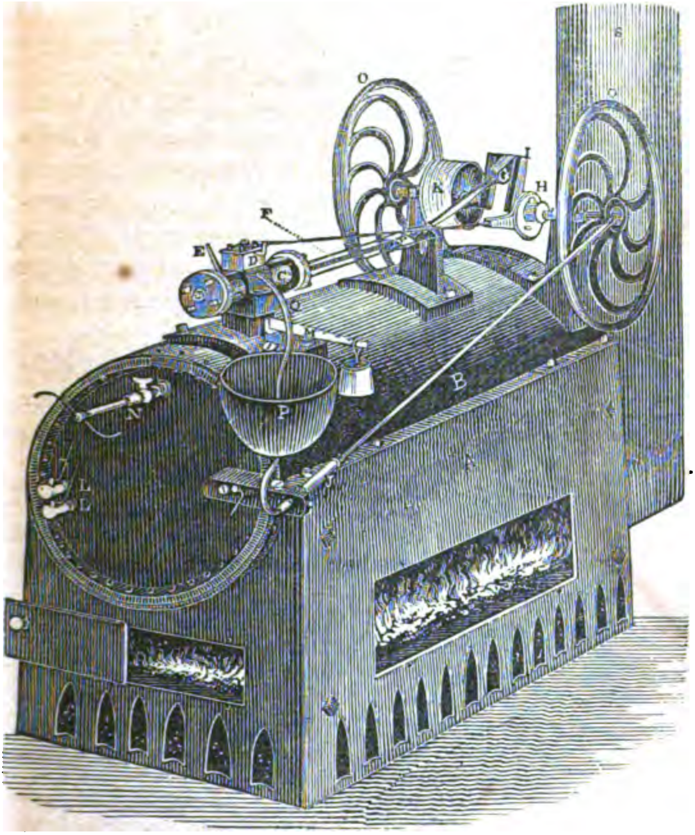
What will be the effect if the condenser be dispensed with? What are high-pressure engines? Some of the advantages of high-pressure over low-pressure engines? Where are high-pressure engines chiefly used? Point out the parts of the high-pressure model, Fig. 116.

wheels or regulators, O, O; K, the pulley or drum, over which runs the belt connecting with the machinery to be driven;

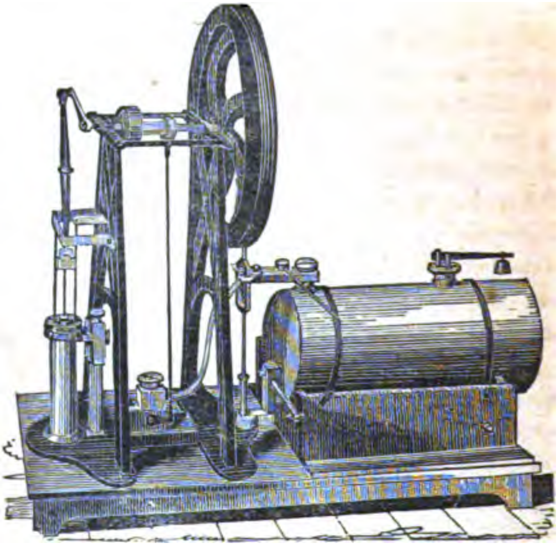
Fig. 116.



H, the eccentric, to which is attached the valve-rod leading to the steam-box; M, the lever of the safety-valve; Q, the eduction-pipe leading from the cylinder and entering the open cistern, P, where it is partly condensed, and forced again into the boiler by means of the force-pump, J.

Fig. 117 presents a *Working Model of the Upright Cylinder High-Pressure Engine.* The parts of this may be learned far more readily by witnessing its operation, than from any written description.

Fig. 117.



Remark. — Water freed from air will not boil at 212° ; if the access of air to such be prevented, and the temperature be raised to 270°, and above, the whole mass of liquid may become highly explosive, exploding with the force of gunpowder. Experiment shows this to be especially true when a very small quantity of common water is suffered to enter the heated liquid. This is thought in many instances to be the cause of the fearful explosions of steam-boilers, — the water of the boiler being freed from its air by ebullition, and the feed-water admitted when this is at a high temperature, causes the whole to explode with a force far exceeding that of steam at the pressure indicated.

Various attempts have been made of late to substitute *hot air*, ether, vapor, etc., for the steam from water, but as yet without success. The bi-sulphuret of carbon, however, is said to have been recently used, and the experiment to promise success. (See *Scientific American*, June 30, 1855.)

What does figure 117 represent?

METEOROLOGY.

109. Meteorology *treats of the various phenomena of the Atmosphere.*— The atmosphere which envelopes the earth may be regarded as a vast laboratory, in which nature, through the agencies of heat and moisture, is working constant changes. Among the more important results of these atmospheric changes may be mentioned the formation of winds, clouds, rain, hail, dew, frosts, etc.

Winds are caused by disturbances in the equilibrium of the atmosphere, produced by heat from the sun and other sources. — Whenever any portion of the earth's atmosphere becomes heated, a rarefaction is the result. This causes the cooler and denser air from the surrounding portions to flow in to this rarefied space, and winds blowing from different quarters are the result. Examples of this are furnished by the sea and land breezes of islands situated in the midst of the ocean.

As the earth receives and imparts the heat derived from the sun far more readily than the water does, the atmosphere incumbent upon the former becomes more heated and rarefied during the day; this causes the air over the land to ascend, while the cooler and denser portions from the ocean flow in on all sides to fill the partial void; and, hence, the cool sea-breeze that is usually felt in such situations during the middle of a summer's day.

As the sun declines at evening, the land, which parts more readily with its heat, soon becomes cooler than the water. The atmosphere resting over it, also partaking of the change, the sea-breeze gradually dies away; during the night the aerial currents are reversed, and blow from the land towards the ocean, causing the land-breeze of the morning. With the heat from the ascending

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Of what does Meteorology treat? The more important results of the changes which take place in the atmosphere? How are winds produced? Give an explanation of the causes of the sea and land breezes.

sun, a sea-breeze is again formed; and so the change is repeated. These sea and land breezes are more marked in tropical latitudes, where the heat of the sun is more intense.

They are also experienced to a certain extent for a few miles inland, along the main coast bordering upon the ocean, and afford an agreeable relief from the heat of the summer's sun.

The same cause of winds is sometimes illustrated, on a less extended scale, in the burning of buildings during a calm evening, when a gentle breeze may be perceived setting in on all sides towards the heated space.

The violent winds frequently attending powerful rain-storms are supposed to be produced by the rapid condensation of the vapor of the atmosphere in the form of rain. The great reduction in volume, caused by such a condensation of vapor, produces a sudden rarefaction of the air, which causes the surrounding portions to rush in with violence to fill the rarefied space, thus giving rise to the terrific winds often experienced during such storms, especially in tropical latitudes.

110. *Whirlwinds* are caused by the meeting of winds from different quarters so as to produce a gyratory or whirling movement of the air. The tendency of the central portion of these is usually upwards, as seen by the course of the light bodies taken up by such in their passage across an open field. In tropical regions these whirlwinds are often extremely violent, constituting *hurricanes* and *tornadoes.** When these whirlwinds

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* The terrific force of the wind in tornadoes was seen a few years since in one which passed over and devastated a portion of the island of Guadaloupe. Houses firmly built were demolished; cannons were hurled from the top of the parapets of the batteries on which they were planted; a thick plank, three feet in length and eight inches in breadth, was driven with such a force through the air that it perforated a palm-tree about seventeen inches in diameter, through and through.

How is the cause of winds shown in the burning of buildings during a calm evening? Cause of the violent winds often accompanying rain-storms? How are whirlwinds produced? What is said of these in tropical regions?

pass over bodies of water, if sufficiently violent, they produce *water-spouts.*

Trade Winds.—These are winds which prevail in tropical latitudes, and usually extend to a distance of about 28° or 30° on each side of the equator. Their direction is from the north-east towards the south-west on the north side of the equator, and from the south-east towards the north-west on the south side of the equator, meeting and merging at the equator into a direct east wind. The direction of these winds is uniform throughout the whole year, except where certain local causes interfere.

The trade winds are the result of two causes combined, namely, the rarefaction of the air of the torrid zone, produced by the heat of the sun, which causes the colder air of higher latitudes to flow in towards the equator, and the rotary motion of the earth on its axis from west to east, causing these winds to fall behind, or have a tendency towards the west, as they approach the equator, where the velocity of the earth's surface becomes greater. The trade winds were so called because of the facilities which they afford to vessels engaged in trade and commerce.

111. *Mists* or *clouds* are formed from the watery vapor of the atmosphere condensed by cold so as to become visible. Atmospheric air is capable of taking up and holding in solution a great amount of vapor. This becomes visible only when the air in which it is dissolved is cooled to a certain point, when it assumes the form of minute vesicles or floating bubbles, and appears as a mist or cloud.

The quantity of watery vapor which a given volume of air will hold in solution, depends on its temperature, increasing with this, but not in the same ratio. If a body of air at a

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Where do the trade winds prevail, and what is the direction of their course? Two causes of these? Why called trade winds? From what are clouds formed? What is said of atmospheric air in its relations to watery vapor? On what does the quantity of vapor which a given volume of air will hold depend?

high temperature, say 72°, have this increased ten degrees, its capacity for holding vapor will become far greater by such increase, than if its temperature be increased ten degrees when at 32°. Accordingly, if two equal bodies of air, one at 80°, and the other at 40°, when saturated with vapor, meet and commingle, their mean capacity for vapor will not be the same as their mean temperature, 60°, but considerably above this; so that a portion of their vapor will be condensed, and become visible as a mist.

In this manner clouds are supposed to be formed when opposite currents of air, of different temperatures, and saturated with watery vapor, meet.

When a warm current of air, charged with vapor, blows over a cooler surface of land or water, the vapor of the air becomes condensed, and appears as a fog or mist. So, also, when the water is warmer than the incumbent atmosphere, the vapors rising from it will be in like manner condensed. Thus, the warm currents of the Gulf-stream, meeting with the cooler air of the northern latitudes, give rise to the dense fogs which prevail so extensively upon the banks of Newfoundland.

The cause of the rapid formation of thunder-clouds, during a summer's day, is generally due to the vapors carried up by the warm currents rising from the earth's surface, and which are condensed by the cold of the upper regions. *Storms* are usually formed by the meeting of currents of air, of different temperatures, blowing from opposite quarters, and charged with vapors. Clouds which form in elevated regions oftentimes disappear, or are dissolved by sinking down into the warmer air below, which is capable of holding the vapor of these in an invisible solution.

Explain the manner in which vapor may be condensed and become visible by the meeting of two opposite currents of air of different temperatures. Explain the formation of fogs resting down upon the surface of land or water. How are the fogs upon the banks of Newfoundland produced?

112. *Rain.*— When the watery vesicles of a cloud unite and become too heavy to be longer supported by the air, they descend in drops of rain. The quantity of rain falling in a given time depends on the rapidity with which the vapor of the cloud is condensed. In tropical latitudes, where the causes combine to produce a rapid condensation of the vapor, the quantity of rain which falls in a short space of time is often surprisingly great.*

Hail is simply drops of rain frozen by the cold of the elevated regions. Hail-stones, weighing several ounces, occasionally fall, doing serious injury to dwellings as well as vegetation. How these can be sustained in the atmosphere a sufficient time to allow of such formations, has been a question among meteorologists. The cause is, however, usually attributed to whirlwinds, by which a quantity of dense vapor is suddenly transported into the colder regions above, and there supported for a sufficient time to allow of their formation. Hail-storms are confined to the temperate zone, and the time of their duration seldom exceeds fifteen or twenty minutes.

113. *Dew is formed by vapor deposited from the air in contact with cold surfaces.*— Thus, if a tumbler of cold water be placed upon the table, in a summer day, its outside surface usually becomes covered with moisture deposited from the contiguous air. The temperature at which the air will deposit this

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* At Bombay there fell in one day six inches of rain; at Cayenne, ten inches fell in ten hours. The annual quantity of rain which falls at London is about twenty-five inches; at Paris, twenty inches; while that which falls in a single year on the coast of Malabar sometimes reaches one hundred and twenty-three inches, and at St. Domingo, one hundred and fifty inches. During the fall of the torrents of rain in tropical latitudes, the drops are often surprisingly large, and fall with a force sufficient to cause pain where they strike the unprotected surface of the body.

How are rain-drops produced? What is said of rain in tropical latitudes? What is hail? How are hail-stones of a large size probably formed? Where do hail-storms prevail? How is dew formed? Illustrate the formation of dew in the case of a tumbler of water. What is the dew-point?

moisture, or dew, is called the *dew-point.* This varies at different times, according to the amount of vapor with which the air is charged. By placing a thermometer in a tumbler of water, and noting the temperature at which the vapor begins to deposit, the dew-point, and, consequently, the proportional amount of watery vapor in the air, may be at any time ascertained.

The dew formed on leaves and vegetables during a calm, clear night, is caused by the readiness with which such objects part with their heat and become cooled in the absence of the sun. Bodies, such as stones, sand, etc., which retain their heat, or lose it less readily, seldom become cooled, during the night, to a temperature sufficiently low for a dew deposit; and hence, the usual freedom of these from dew.* Clouds suspended over the earth radiate back the heat which they receive from this, and thus prevent the temperature from falling; for this reason dew seldom forms during a cloudy night. From the same cause, straw, etc., spread over vegetables, prevent the formation of dew on these. So winds, which serve to change the layers of air, and bring warm currents of this in contact with the objects on the earth's surface, prevent the formation of dew. *Hoar-frost* is frozen dew.

* The nice discrimination observed in the deposit of dew on various objects may be adduced as one of the numberless proofs of an intelligent, designing Author of Nature. Thus, we see this fertilizing element gather copiously on vegetables, which most require its reviving influence; while bodies of water, stones, sands, and barren wastes, where a dewy deposit would be useless, receive comparatively little moisture from this source. In regions where rain seldom falls, vegetation is in many instances sustained by the copious dew deposited during the night: this is seen in Palestine, and other oriental countries; also in Chili, and along the western coasts of America.

Why does dew form on vegetables rather than on stones, sand, etc.? How do clouds prevent the formation of dew? Why does this not form in windy nights? What is hoar-frost?

SOUND.

114. WHEN a sounding body, as a bell, for instance, is struck, it assumes a tremulous or vibratory motion; this imparts to the surrounding air a series of oscillations, which, impinging on the membrane of the drum of the ear, excite in this also tremulous motions; through the medium of the included air, or the delicate chain of bones connecting with the labyrinth of the ear, these motions are communicated to the fluid which fills this labyrinth, which, acting on the auditory nerve, produces *the sensation of sound.*

Air, as we have already shown, is an exceedingly elastic fluid; and, as elastic bodies are in general the mediums of sound, this becomes the chief vehicle for communicating to the ear the vibrations from sounding bodies.

Aerial oscillations, or sound-waves, are produced in, and traverse the air, in a manner similar to the undulations of water caused by throwing into it a pebble. Thus, if a stone be thrown into a smooth pond, a concussion is produced which imparts to the water a series of oscillations or waves; each layer of water transmitting the vibratory motion it receives, in a somewhat diminished degree, to the next, and so spreading in every direction from the disturbing cause, until the whole surface of the pond is agitated, or the tremulous motion dies away in the distance. So, when a sounding body is struck, a like undulatory movement is produced in the air, which is transmitted, in a manner analogous to that of water, except with far greater facility, causing, as before stated, a sound.

When these vibrations, excited in the air by a sounding body, are uniform and regular, as where a harp-string is struck by

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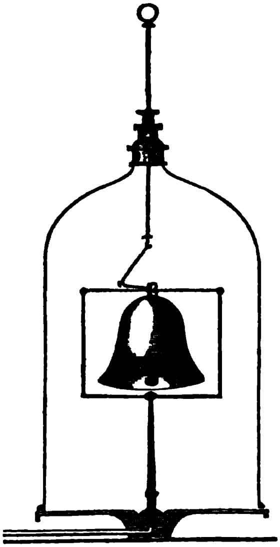
Explain the process by which sound is produced. Why is air the chief vehicle of sound? How do the waves of sound traverse the air? Give an illustration in the case of water.

the finger, a perfect sound, or *tone*, is produced; but if the vibrations take place irregularly, and are not isochronous,* as in the explosion of a gun, a *noise* alone is the result.

115. *Air is, in general, the medium of sound*, although nearly all other elastic bodies are capable of conducting it more or less perfectly. Thus, a sonorous body, properly insulated, becomes inaudible in a space from which the air has been removed. This may be shown as follows:

Fig. 118.



Experiment.—The *Bell in vacuo*, Fig. 118, is a bell insulated, as far as possible, by suspending from a loosely-twisted silk cord placed in a vacuum. Screw the post into the centre hole of the pump-plate; press down the sliding-rod, and attach its string to the handle of the bell, and then cover with the glass, drawing up the sliding-rod at the same time to the position shown in the figure. After placing a drop of oil on the sliding-rod, and seeing that the bell-glass is well fitted to the plate (§ 66), ring the bell by means of the rod. The air, which now fills the receiver and surrounds the bell, will serve as a medium for transmitting its vibrations, and the ringing will be clearly heard. Now perfect a vacuum in the bell-glass, and again ring the bell as before. This has now become inaudible, since the medium through which its vibrations are conducted has been removed by the exhaustion. On gradually admitting the air, the tone becomes louder and louder, with the increasing density of the surrounding air.

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* *Isos*, equal; *chronos*, time.

How is a perfect sound or tone caused? How a mere noise? Give the experiment of the Bell in vacuo.

Sound increases with the density of the air transmitting the vibrations of the sonorous body. This may be illustrated by the following

Experiment a.— Suspend a bell, by means of a small rubber tube prepared for the purpose, in the glass condensing-chamber, Fig. 80. With the stop-cock closed, ring the bell, by giving motion to the chamber, and mark the intensity of the sound; then, with the condenser, force in three or four atmospheres, and ring again as before; the tone will now be perceived to have increased in loudness, with the increased density of the air surrounding the bell.*

Thus, in ascending high mountains, or rising in balloons, the intensity of sound is found to diminish as the rarity of the air increases. Saussure found that on the summit of Mont Blanc the explosion of a pistol appeared no louder than that of a cracker at the surface of the ocean; and aeronauts have often noticed a great diminution in the intensity of the voice at their greatest elevations. On the contrary, the condensed air of the diving-bell (§ 78), when lowered to a great depth in water, is found to conduct sound with such facility as to render even the slightest whisper painful to the ear.

116. *The conducting power of air varies with its uniformity, its density, and humidity.* — Thus, in a calm, frosty morning, before the uniform density of the atmosphere has become disturbed by the sun's heat, the sound of the voice may be often heard to a surprising distance, especially over a level surface, as a body of water. Under such circumstances, conversation

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* By means of a hose connecting this chamber with the air-pump, it may be exhausted, and the bell in vacuo also illustrated.

What is said of the density of air in reference to sound? Give the experiment for showing that sound increases with the density of the air. What is said of sound on high elevations? What is said of sound in the diving-bell? With what does the conducting power of air vary? Give the illustrations.

has been carried on across an intervening space of nearly two miles. The watchword, *All's well!* has been heard from Old to New Gibraltar, a distance of ten or twelve miles;* while the sound of a cannonading at sea is said to have been conveyed to a distance of two hundred miles. Sounds are also peculiarly clear and loud in a humid atmosphere, such as usually precedes a storm. This, however, is not attributable, as is sometimes supposed, to an increased density of the air, but rather to the superior facility of the watery particles for conducting sound.

117. *Solids as well as liquids are in general better conductors of sound than air.* — Thus, the scratch of an awl at one end of a series of pump-logs properly joined, will be distinctly heard by the ear, applied at the other, although scarcely audible through the air, to the person making it. So, by resting the ear upon the iron rail of a railroad, the approach of a train of cars, or the strokes from the hammer of a workman, may be heard for miles. In this manner the conducting power of the earth enables the American Indian to distinguish, at a surprising distance, the tramp of buffaloes, or the proximity of an enemy.

It is easy to ascertain whether a kettle boils, by placing one end of a stick, or poker, on the lid, and the other end to the ear; the bubbling of the water then appears as loud as the rattling of a carriage in the street. A slight blow given to a steel poker, or triangle, of which one end is held to the ear, produces a sound even painfully loud. Two persons stopping their ears and holding a stick between their teeth, may hold conversation through the conducting power of the stick and the solids of the body.

The fact of solids conveying sounds more readily than air

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* Olmsted's Philosophy.

What is said of a humid atmosphere for conducting sound? To what is this attributed? What is said of the power of solids and liquids for conducting sound? Give illustrations of the conducting power of solids.

led to the discovery of the *Stethoscope*. This instrument consists of a wooden cylinder, which is applied to the surface of the body, over any internal organs, as the lungs, for instance, and thus, by sounds conveyed through this to the practised ear, the healthy or diseased condition of these internal organs is determined with nearly the same accuracy as though seen by the eye itself.*

The superior conducting power of solids over air was determined by a series of experiments performed by M. Biot, who availed himself of the laying of a train of iron pipes arranged for conveying water into Paris. By suspending a bell in the cavity, at one end of the series, so that a hammer should strike this and the inside of the pipe at the same instant, the comparative power of the air and metal for conducting sound was determined.

By these experiments it was ascertained that cast-iron conducts sound about ten times as rapidly as air.

118. *Liquids are also good vehicles for sound.*—Thus, if the head be held beneath the surface of the water, and a person upon the opposite side of a pond, a half a mile or more distant, strike together two stones in the water, the sound of the concussion will be distinctly conveyed to the ear through the water, although through the air the same would be audible but a few feet. M. Colladon heard the sound of a bell, struck under water, across the whole breadth of Lake Geneva, a distance of nine miles; this appeared to be conveyed through the water with about four times the velocity that sound ordinarily traverses the air.

119. *The velocity of sound is progressive*, and in air, at the surface of the ocean, and at a temperature of 62°, has been ascer-

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* Dr. Arnott.

Principle on which the Stethoscope acts? Describe this and its uses. State the experiments of M. Biot. How much more rapidly does iron conduct sound than air? What is said of the conducting power of liquids? Give an illustration. What is said of the velocity of sound, and the distance it moves in a second?

tained by careful experiments, to be very nearly 1125 feet per second. Hence, by knowing the rate at which sound travels, the distance of a sounding body, as a cannon for instance, may be easily determined, and with a good degree of accuracy.

This is ascertained by multiplying the number of seconds which elapse after the flash before the report or thunder is heard, by 1125, and then reducing this product to miles, by dividing by 5280, the number of feet in a mile. Thus, if a flash of lightning is seen fifteen seconds before the report is heard, $1125 \times 15 \div 5280$, gives very nearly 3.19 miles, the distance of the discharge.*

The marching of a long procession to music affords a good example of the progressive nature of sound. Thus, while each platoon keeps step to the music, as it is heard, a gradual variation will be seen along the whole line, those in the rear, and most remote from the music, may be seen, perhaps, an entire beat behind those in the front ranks.

120. *Reflection of sound.*—When the vibrations or sound-waves excited in air, impinge against any plane solid surface, they are reflected or thrown back the same as when the waves of water strike against a wall or other body; this reflection, or return of sound to the ear, occasions an *echo.* Sound-waves follow the same laws of reflection which govern more ponderable matter, and are always reflected at the same angle at which they strike a surface; so that, to hear an echo of his own voice, the person must stand directly before the surface from which it is last reflected.

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* Since light moves with an immense velocity (200,000 miles per second, nearly), for any distance on the earth's surface, it is regarded as instantaneous.

How may the distance of a sounding body, as a cannon for instance, be determined? Give an illustration of the progressive movement of sound in the marching of a long procession What is said in regard to the reflection of sound? What is an echo?

The quickness with which an echo is returned depends, of course, on the distance, so that an object situated at half the distance which sound traverses in a second, say five hundred and sixty-two feet, would return a sound, to the person originating it, in just one second; so that if the reflecting surface be sufficiently remote, several syllables or a short sentence may be uttered, and receive a distinct return. At Lurleyfels, on the Rhine, there is an echo which repeats seventeen times.

The echo of the Capo di Bouve, as well as that of the Metelli at Rome, was celebrated among the ancients. It is a matter of tradition that the latter was capable of repeating the first line of the Æneid, which contains fifteen syllables, eight times distinctly. An echo in a building at Pavia is said to have answered a question by repeating its last syllable thirty times.

Sound is reflected from concave surfaces, and collected the same as light and heat; hence, beneath domes and arched ceilings, the sound of the voice becomes often quite painful. A notorious instance of a sound-collecting surface was the *ear of Dionysius*, in the dungeons of Syracuse. The roof of the prison was so formed as to collect the words and even the whispers of the unhappy prisoners, and to direct them along a hidden conduit to where the tyrant sat listening. The wide-spread sail of a ship, rendered concave by a gentle breeze, is also a good collector of sound. By this means the sound of bells rung at St. Salvador was heard on the deck of a vessel one hundred miles distant.*

121. *The Speaking-Trumpet.* — This is an instrument employed by commanders of vessels, generals of armies, and

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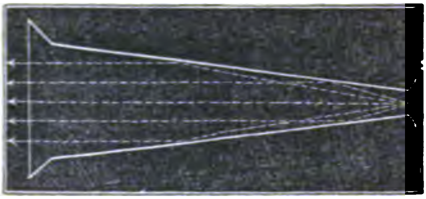
* Arnott's Physics.

Upon what do the number of echoes from a surface depend? What illustrations are given? What is said of sound reflected from concave surfaces? Example in case of the ear of Dionysius? The sail of a ship? By whom and where is the Speaking-Trumpet used?

others, for transmitting their orders during the noise of the tempest, or the din of battle. The rays of sound, proceeding from the mouth when applied to the trumpet, instead of diverging and being scattered through the surrounding atmosphere, are reflected from the sides of this instrument, and conducted forward in straight lines, thus giving great additional power to the voice. The course of the rays of sound, proceeding from the mouth through this instrument, may be shown by Fig. 119, which exhibits a common form of the speaking-trumpet.

Fig. 119.



122. *Musical Sounds.* — Sound, as we have already remarked, is the result of vibrations excited in air or other elastic media by a sounding body. When these vibrations of the sounding body occur at sufficient intervals, so as to be seen by the eye, the impulses given to the air will be attended to separately by the ear, and a *noise* only will be produced; but, if these be repeated with sufficient frequency, the ear will be unable to distinguish the separate vibrations, and a continuous sound or *tone* will be heard. Thus, if the string of a bass-viol be sufficiently slack, its vibrations may be seen, and only a harsh, disagreeable sound will be produced; but, as the tension of this is increased, its vibrations become more rapid, until it gives forth a smooth and agreeable tone.

The *pitch* of a musical chord depends on the number of vibrations it makes in a given time, and these vary with the length, the diameter, and the tension of the chord. Thus, with a given diameter and length, *the greater the tension* the more frequent

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How does this instrument aid the voice in transmitting commands? What does Fig. 119 show? How are Musical Sounds produced? Illustration? On what does the pitch of a musical chord depend?

will be the vibrations, and consequently the higher the pitch or tone. And, again, with a given length and degree of tension, *the less the diameter* of the chord the higher will be its tone While, again, with a given diameter and tension, *the less the length*, the higher the tone of the musical chord.

These truths are familiarly illustrated in the violin. The low or base string is thick and heavy from being covered with fine wire, while the others gradually diminish in size and weight up to the smallest or treble. These strings are tuned to each other by being attached at one end to movable pins, which, when turned, increase or diminish their tension. The sound then produced by each may be varied to a certain extent by the performers pressing the string at different points with the fingers, so as to vary the length of the vibrating portion.*

When a musical tone is produced by a definite number of vibrations of the sounding body, it is termed a *note*. A collection of eight consecutive notes forms an *octave;* and one octave is said to be higher or lower than another when the notes it contains are produced by a greater or smaller number of vibrations in a given time. Thus, if a particular note of any octave be produced by a given rate of vibration, the vibrations producing the corresponding note of the next octave below will be *one half*, and of the next above, *twice* as rapid. These notes constitute the *diatonic* scale or *gamut*. The English names for these, as well as the ratio of vibrations corresponding to each, are as follows:

C	D	E	F	G	A	B	C
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

Thus, these eight notes constitute the *scale* or steps by which the voice naturally ascends from any tone to the corre-

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* Arnott.

How do vibrations of such a chord vary? Give an illustration in case of the violin. What is a note in music? An octave? When is one octave said to be higher or lower than another? Why are these eight notes called the scale?

ponding tone above produced by vibrations twice as rapid; and however far this musical scale be extended, it will still be found but a repetition of similar octaves.

123. *Wind Instruments*, as the flute, the organ, etc., emit sounds from the longitudinal vibrations of the column of air confined within their tubes. As with musical strings, these vibrations vary according to the length of the tube, being more frequent as these are shorter. When one end of the tube is closed, the note is rendered twice as grave, since the sound-wave has to return after passing in. The length of the air vibrations and pitch of the tone are regulated by the opening and closing of holes arranged along the side of the tube, as in the pipe and flute.

Musical tones, by whatever instrument produced, have to each other the same numerical relations as the vibrations which constitute them. The different qualities of tone, therefore, from different instruments, can only depend on the peculiarities of the single vibration, as to whether they are sharp or soft, strong or weak.

The cultivation of no art exerts a more refined and humanizing influence than that of music. The simple, yet expressive songs of the school-room and the nursery shed over the mind and character an influence often felt through all the devious course of subsequent life. How often does the sound of some favorite air, learned during the agreeable recreations of innocent childhood, revive all that was dear in home and kindred, and point the wanderer back to duty! Music is the language of nature; intelligible at once to all susceptible minds, and, in a degree, even to the inferior animals. Yet the love of novelty and fashion among *professors* in the art often throws over it so many ornaments and accompaniments, that the *melody*, in which

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What is said of octaves above or below a given octave? What is said of the vibrations in wind-instruments, as the flute, etc.? Of the relations of the vibrations which produce musical tones? What is said in relation to the influence of music? Of the fashionable tricks of the voice by some professors of the musical art?

the idea and sentiment really reside, is masked and lost. Some of the tricks on the voice and on instruments, at present so common, are to natural or graceful music what tumbling and rope-dancing are to natural and graceful gesture.

124. No instrument is capable of producing sounds of greater variety and melody than that which forms the human voice. This consists of two delicate membranes situated at the top of the wind-pipe, with a slit or opening, called the *glottis*, left between them for the passage of the air. By varying the tension of these membranes, and the size of the opening, the innumerable variety of tones of which the voice is capable is produced.

The human voice has been in some instances so trained as to be capable of imitating with a wonderful degree of accuracy the various instruments of a musical band, as the bugle, the clarinet, etc. A band of twelve Germans, a few years since, performed in some of the European cities a variety of difficult airs, as waltzes, polkas, etc., imitating, with their voices alone, as many different musical instruments.

The art of *Ventriloquism* * consists in the power of the performer so to modulate and vary his voice as to imitate different sounds at varying distances, and thus to deceive the judgment of the listener in regard to the direction from whence these proceed. Thus, the sound of voices apparently at a distance, as, for instance, of two disputants engaged in angry debate, may be created by the operator, so as to appear to the bystanders as a reality.

The art of imitating sounds, as seen in the case of the ventriloquist, is in a great measure the result of careful practice. Thus, almost any person possessed of a good ear for sounds

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* *Ventri*, from the belly, and *loquor*, to speak.

What is said of the organs or instrument by which the human voice is formed? Of what does this instrument consist? In what does the art of Ventriloquism consist? How are these illusions of the voice produced?

may, by habitual practice, become able to imitate the varying tones of voice of others, and the sounds of different animals, with great precision.

The mechanism of the ear, whereby sound is produced, and the sensation conveyed to the brain, is truly wonderful. This, in the human species, consists of three distinct parts. The external and visible part of the ear serves, like the mouth of an ear-trumpet, to collect the rays of sound, and reflect them inwards, through a gradually contracting tube, to an aperture within the skull, covered by a delicate membrane tightly stretched over it. Behind this membrane is a chamber, filled with air, known as the *tympanum*, or drum of the ear. Thus, the least concussion of the air without causes this membrane to vibrate and produce the sensation of sound.

From this chamber of the drum leads the eustachean tube, opening into the mouth, and so forming a free communication between it and the external air, whereby an equilibrium of pressure is constantly maintained. Whenever this tube, from any cause, becomes filled so as to interrupt the free communication with the external air, a humming sound or ringing in the head is produced. At the inner extremity of the chamber just mentioned is a second opening, called the *fenestra ovalis*, covered by a second elastic membrane, which completes the analogy of the drum. Various other delicate appendages serve to complete the apparatus of this wonderful organ.

PRACTICAL PROBLEMS.

1. If the pressure of steam upon the boiler of a locomotive be 65 lbs. against a square inch, what would be the entire force of this acting against a surface of 60 square feet?

What is said of the art of imitating sounds? Of how many parts does the ear consist? Use of the external part of the ear? Describe the tympanum Cause of the humming sound sometimes heard?

2. In such a locomotive, what would be the amount of pressure against a piston 12 inches in diameter?

3. If the evaporation from a square foot of ground was found in 12 hours to be 2 gills, how many gallons would evaporate from a square acre in the same time?

4. The discharge of a gun from a frigàte was seen 28 seconds before a report was heard; allowing sound to travel 1,125 feet per second, how far distant was the frigate?

5. A flash of lightning was seen 13 seconds before the thunder was heard; what was its distance?

6. A person saw the flash of a cannon fired from a ship 4 miles distant; how long after, if at all, did he hear a report?

7. How long after a sudden shout will an echo be returned from a cliff 80 rods distant?

8. If a gun be fired, and the sound returned from a wood in $2\frac{3}{4}$ seconds, how far distant is the wood?

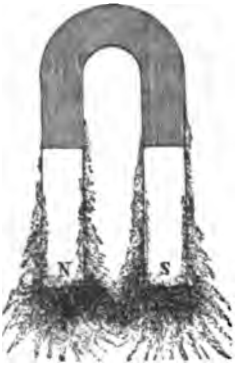
9. Wishing to ascertain the depth of a cavern which could not be descended into, a stone was dropped and seen to strike some water at the bottom two seconds before a report was heard; how deep was the cavern?

10. In the bombardment of a certain fortress a shell fired from a frigate was seen to enter and instantly explode the magazine, a report of which reached the frigate in 10 seconds after the explosion; what was the distance the shell was fired?

MAGNETISM.

125. The remarkable property, possessed by certain ferruginous ores, of attracting iron, was well known to the ancients. These ores were termed *Magnets*, from *Magnesia*, a town of Lydia, where they were said to abound.

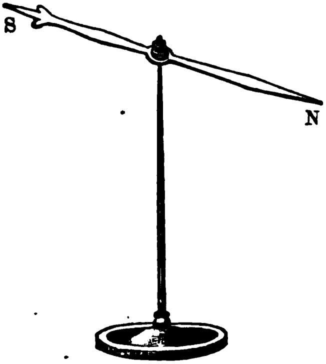
Fig. 120.



This natural magnet, or, as it is generally termed, *lodestone*, has the power of producing similar magnetic qualities in iron and steel, when brought in contact with it, and rendering them also magnetic. These latter are therefore termed *Artificial Magnets*.

If iron filings be sprinkled over a bar-magnet, these will be found to adhere about the ends, arranging themselves in a certain order, as seen by Fig. 120. These extremities, where the magnetic action seems concentrated, are termed the *poles* of the magnet.

Fig. 121.



Let a magnetized bar or needle of steel or iron be suspended by a thread, or balanced on a pivot, Fig. 121, so that it shall be free to revolve in a horizontal direction, and, it will be found after a few oscillations to arrange itself in a north and south direction. If, now, this be

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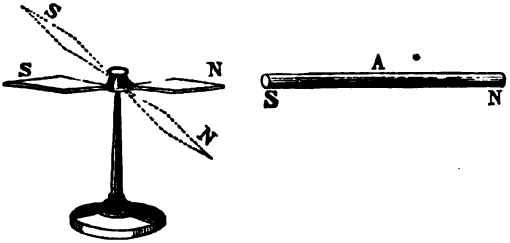
Were the properties of the Magnet known to the ancients? Origin of the term Magnet? What is said of the power of lodestone in reference to the formation of Artificial Magnets? What does Fig. 120 show? What are the poles of the magnet? How will a magnetized bar, free to move, arrange itself?

turned by the hand, so as to reverse the ends, these will be found at once to return to their former position when the force is removed. From the direction which these poles always take, the one pointing to the north is commonly termed the *north* pole, and the one to the south, the *south* pole, and are marked with the corresponding initials, as shown in Fig. 121.

126. *The like poles of two magnets repel, and the unlike attract each other.*—Thus, in Fig. 122, if to its north pole the south pole of a second magnet be presented, the two poles will strongly attract each other; but if the north pole of the magnet, A, be presented to the same pole of the other rotating magnet, the latter will be repelled, as shown by the dotted space; and, if both magnets be free to move on a pivot, the repulsion will be shown to be mutual. Thus two magnetic fluids are supposed to exist in the molecules of the metal, known as the *austral* and *boreal* fluids, and corresponding in their effects to the positive and negative electricities of the succeeding section.

Fig. 122.

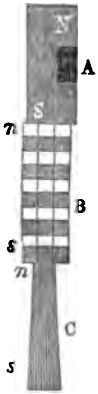


127. *A magnetized steel bar induces magnetism in another iron or steel bar in contact with it.*—If a straight magnet, A, Fig. 123, be applied to a bar of iron, B, this will also assume magnetic properties, and become itself a magnet, as may be shown by applying to its lower extremity another bar of iron, which will be attracted, and also rendered magnetic.

State the proposition. Illustrate this attraction and repulsion of the magnet by Fig. 122. What fluids are supposed to exist in the magnet? Give proposition, § 127.

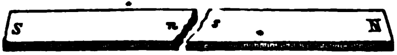
In this case no transfer of the magnetic fluid is made, but simply an influence is exerted by the magnet, A, over the fluids existing in a combined and latent state in the metals, B and C, whereby these fluids are supposed to be separated in each molecule of these metals, and rendered free. Thus, each one of these invisible particles of the iron becomes itself a magnet with north and south polarity. The arrangement of these elementary magnets may be shown by the light and dark shading of the bar, B; the former indicating the north, and the latter the south pole of each atom. Thus, the like poles of these several little magnets are all seen pointing in the same direction, causing the extremities of the magnet to be always of opposite polarities. This theory explains the cause of the increase of the magnetic force towards the ends of a magnet, and the entire want of this in the centre; for the last row of atoms, having no others to oppose their action, will exert the ordinary attractive and repulsive effects of free magnetism, while, in the centre, this is entirely destroyed by counter forces of the adjacent atoms.

Fig. 123.



The fact of the magnetic fluids being inseparable from the atoms of a magnetic bar, as just supposed, explains also the fact, that when such a bar is broken in two parts, as seen in Fig. 124, each of these parts becomes a perfect magnet, having opposite polarities. Thus, as shown in the figure, the fractured end of each piece at once exhibits a polarity the reverse of that at the extremities of the original magnet, although at this middle point, where *s* and *n* join, no

Fig. 124.



Illustrate this by Fig. 123. How is the effect of the magnetic influence in this case supposed to be produced? State the theory of the magnet, as illustrated by Fig. 123. What does the fact of these fluids being inseparable from the particles of the magnet explain?

magnetism could be detected before breaking. If these pieces be again divided, and then subdivided, the same results of perfect magnets will be seen.

128. *Soft iron acquires and loses magnetism far more readily than hardened steel.* — Thus, in Fig. 123, the bar of soft iron, B, retains its magnetic properties only so long as it is in contact with or proximity to the magnet. Remove it from this, and the separated magnetic fluids at once come together, and are thereby rendered neutral as before. This is shown by C falling off as soon as B is separated from the magnet A. If a piece of hardened steel be brought in contact with the magnet, the inductive effects of this will operate more slowly, requiring some time before the remote end will have acquired its opposite polarity. Hence it is that electro-magnets, where the magnetic effects imparted require to be instantaneous, are made of soft iron, while common lifting magnets are prepared from hardened steel.

Fig. 125.

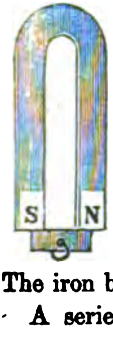
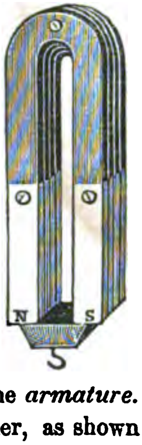


Fig. 126.



129. *Artificial Magnets* are made from steel, and are of a variety of forms, depending on the uses to which they are to be applied. The U-magnet, Fig. 125, is a more common form for a lifting magnet, since the opposite poles or extremities are brought near together and may be joined so as to exert their united forces on the body to be raised. The iron bar which unites the two poles, is called the *armature.* A series of such magnets firmly joined together, as shown by Fig. 126, constitutes a *Magnetic Battery.*

To Magnetize a Steel Bar. — If straight, place the middle

What is said in regard to soft iron and hardened steel? Why are electro-magnets made of soft iron? Of what are Artificial Magnets made, and why usually made in the form seen in Fig. 125? What is the armature? What is a Magnetic Battery?

of the bar on one of the poles of either a straight or a U-magnet, and draw one end of it over the pole a number of times; the direction of the motion being always from the middle to the end. Then turn the bar in the hand, and pass the other half over the other pole of the magnet in the same way. If the bar is thick, the process may be repeated with its different sides. The end which has been drawn over the south pole of the magnet will now possess north polarity, and the other extremity south polarity. A U-magnet is more readily charged by drawing over it the poles of a steel U-magnet of corresponding width, from the bend to the extremities. This should be repeated several times, recollecting always to draw the bar in the same direction. When it is of considerable thickness, turn it, and repeat the process with its opposite surface, keeping each half applied to the same pole as before. To withdraw the magnetism from a steel bar it is only necessary to *reverse* the above processes.*

In order to retain and increase the magnetism of a magnet, its two poles should be joined by an armature, through which these may reäct on each other; otherwise, the two fluids in the steel bar will gradually unite and become neutral.

130. *Magnetism induced by the Earth.*—If a straight bar of soft iron, about two feet in length, be placed at the angle of the dip of the magnetic needle (§ 133), it will gradually acquire magnetism from the earth; the lower extremity becoming a south, and the upper a north pole, as may be shown by bringing near the ends one of the poles of a needle. In this way tongs and various articles of house furniture, the tools of a workshop, etc., often become magnets. In such a position, induction of magnetism by the earth is greatly facilitated by blows

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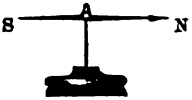
* Davis' Manual.

State the process by which magnetism may be imparted to steel bars. How may a bar of soft iron be rendered magnetic from the earth?

with a hammer, twisting, etc., so as to cause a vibration or movement among the particles of the metal. This process of magnetizing is most effective when the bar rests upon a mass of iron. The permanency of a magnet depends no doubt on the hardness of the metal and the compactness of the particles, which thereby prevents the ready union of the two fluids in the particles of the metal.

Blows upon a magnet, when placed in a horizontal direction east and west, will often remove its magnetism. So blows from the fall of a magnet may serve to destroy or injure it. Heat, also, weakens, while cold serves to increase, the strength of a magnet.

Fig. 127.



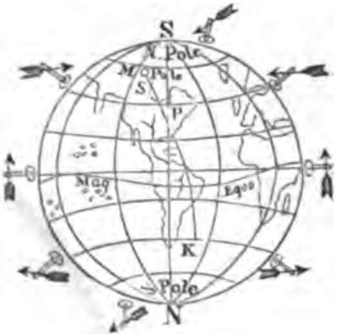
131. *Direction of Magnets.* — As we have already shown, a magnetized bar, when balanced on a pivot and free to move, as shown by Fig. 127, takes a nearly north and south direction, obedient to a force termed the earth's magnetic force. Such a magnet of the proper form constitutes the magnetic needle. This force, which gives definite direction to the magnet in every quarter of the globe, is found to reside near the poles of the earth, and to be a magnetic force. Thus, the earth is supposed to be a huge magnet, with its opposite poles coinciding nearly with those of the earth itself; that at the north being termed the *magnetic north pole*, and the other at the south the *magnetic south pole.* This supposition is confirmed by the fact of the magnetic intensity being greatest at a point near the pole of the earth, and gradually diminishing, as the equator is approached, until a neutral point is reached, similar to that between the poles of an artificial magnet.

This neutral line constitutes the *magnetic equator*, and

What are some of the ways in which the magnetism of a bar may be injured or destroyed? What is the magnetic needle? Where is this magnetic force found to reside? What is said of the supposition in regard to the earth as a magnet?

forms an irregular circle around the earth, deviating more or less from the terrestrial equator, crossing it at certain points, and passing sometimes north and sometimes south of this. Thus, in the Atlantic Ocean, at 25° 40′ west from Greenwich, the magnetic equator reaches a point of 14° south latitude, approaching the terrestrial equator, as it extends west, until it meets this at a point 117° 40′ west from Greenwich, when it again makes a southern curve. At 172° 20′ west longitude, it crosses the earth's equator, passing along in north latitude until it reaches 20° 20′ east longitude, where it again intersects the terrestrial equator, and so traversing in an irregular curve around the earth. The course of the magnetic equator, as well as the position of the magnetic poles, may be learned from Fig. 128.

Fig. 128.



132. *The Declination of the Magnetic Needle.*— Since the magnetic axis does not coincide with that of the earth, the magnetic needle is also found to vary at most points from a true north and south line. This variation of the needle, at any place, is termed its *declination.* This declination is *east* or *west*, according as the magnetic needle deviates towards one side or the other of the true astronomical meridian.* That point on the earth's surface where the two meridians

* Thus, in Fig. 128, S N may represent the meridian of a place, and S K the magnetic meridian; then S P S will be the declination at any point.

What is the magnetic equator and its course? Point out this, as shown by Fig. 128. What is meant by the declination of the magnetic needle? Illustrate this by Fig. 128. What is the line of no variation?

coincide, is termed *the line of no variation*, as here the needle points in a true north and south direction. This line appears to traverse the surface of the globe, passing in 1660 through the meridian of London, and from that time moving westward until 1818, when the magnetic needle at that point reached its maximum declination, 24° 18′, and has since been returning eastward to its former direction.

Such declinations of the magnetic needle, occupying a long series of years for their completion, are termed *secular* declinations.* Besides these, it has also daily variations, of only a few seconds of a degree, which are supposed to be caused, in some way, by the agency of the sun's heat upon the earth's surface. In these the south pole of the needle moves towards the west from sunrise until about an hour afternoon, when it retrogrades towards the east until eight o'clock in the evening, after which it remains nearly stationary until sunrise. The Auroræ Borealis is found also to cause the needle to vary considerably at times; the extent of these variations, or perturbations as they are more commonly termed, corresponding with the height to which the streams of auroral light ascend above the horizon. Electrical discharges also often affect the direction of the needle; sometimes reversing its poles or destroying entirely its magnetism.

133. *The Inclination or Dip of the Magnetic Needle.* — From numerous observations made at various points, we are led, as already remarked, to regard the earth as a great magnet, whose poles are situated within a few degrees of the geographical poles, and whose equator, or line, where the magnet is equally attracted and maintains a horizontal position, as forming an irregular

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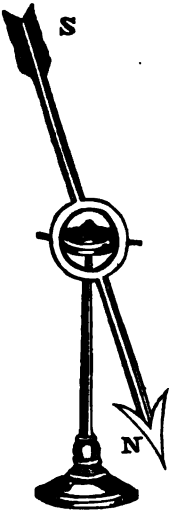
* The declination of the needle at Boston at the present time, January, 1856, is 10° 54′ west of north.

Does this change from time to time? What are secular declinations? How are the daily declinations of the magnetic needle supposed to be produced? What is said of the Aurora Borealis in reference to the magnet? Of lightning? What is the dip of the magnetic needle?

circle about the earth in the vicinity of the geographical equator. The magnetic poles of the earth act upon those of the magnetic needle in a manner similar to those of a powerful artificial magnet, causing the needle to be attracted and incline toward either pole, when made to approach it from the equator. This inclination of the magnetic needle is termed its *dip*. Fig. 129 represents a *dipping needle* for showing this dip of the magnet. This is so balanced as to move in a horizontal or vertical direction. The dip varies with the latitude approaching the magnetic pole. Thus, at Boston, situated in about 42° 20′ north latitude, the dip is at present 74° 21′, and increases as we advance north, until, in the vicinity of Hudson's Bay, in about latitude 70° 5′, it was found, by Sir James Ross, in 1831, to be 90°, or vertical with the horizon. The varying positions of the needle, with reference to the magnetic poles of the earth, are shown by Fig. 128.

Fig. 129.



134. Instruments for measuring the declination are sometimes termed *Declination Compasses*. These are of various forms; as the common surveyor's compass, the mariner's compass, etc. The *Surveyor's Compass* is usually a circular box, attached to a universal joint, placed upon a stand of three legs. Upon the bottom of this box, beneath a nicely-balanced magnetic needle, is pasted a circular card, graduated and marked to denote the points of compass, like that seen in Fig. 198, Electro-Magnetism. This card is so arranged that its north and south points shall be parallel to, or in a line with, a sight or telescope. When the sight, or telescope, is in a range with the object, the angle which the needle makes with the north and south points of the

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How does this vary in different latitudes? Describe the Surveyor's Compass.

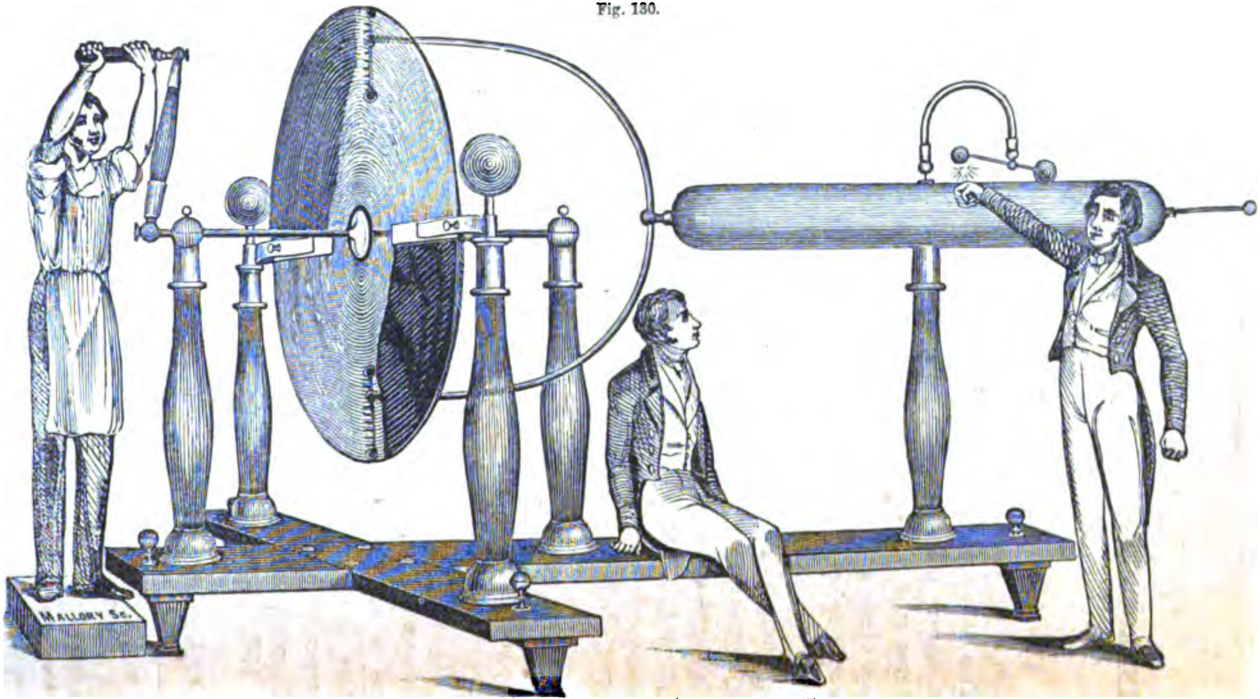
card is the angle of declination, or the bearing of the object from the magnetic meridian. The *Mariner's Compass* is another form of the declination compass, used for directing tho course of a ship at sea. The box for the needle is so arranged as to keep constantly horizontal, and secure this as far as possible from the attractive influence of the iron of the vessel.

Iron was formerly supposed to be the only substance subject to magnetic influences. The researches of Dr. Faraday have, however, disclosed a very wide circle of bodies subject to the same influence. It is indeed difficult to guess at the limit which may exist to the power of magnetism in controlling or influencing molecular forces. The elaborate investigations of this distinguished philosopher have opened out a rich field of promise. A force which a few years ago was supposed to influence pieces of iron only, is by these researches shown to act upon almost every form of ponderable matter.* This will be illustrated in a subsequent section.

* Bird.

Describe the Mariner's Compass and its proper position. What was formerly supposed in regard to iron? What have the late researches of Dr Faraday disclosed?

Fig. 130.



AMERICAN ELECTRICAL MACHINE.

INTRODUCTION TO ELECTRICITY, AND DESCRIPTION OF INSTRUMENTS.*

135. NATURAL phenomena usually excite interest in proportion to the sublimity and mystery which attend their exhibition. This is especially true of *electrical* phenomena. No agent in nature presents itself under a greater variety of wonderful forms than Electricity; and yet with the essence and properties of none are we less acquainted. Now its secret agency works silently in the production of the vapor which rises to form the storm-cloud, and now again is seen in the terrific lightning which darts from this same cloud. In one form its mysterious power is exerted in effecting the decomposition of organized matter, and the separation of this into its original elements; in another, in the recomposition of these same elements to form new compounds. Here we behold this wonderful agent obedient to the will of man,— a vehicle of thought to bear with the speed of thought tidings to distant regions; while, in another quarter, this same agent is seen traversing the heavens and lighting up the polar zone with the brilliant coruscations of the Aurora.

Thus has the identity of Electricity with the most wonderful phenomena of nature ever rendered it of interest in all ages, and to all classes of community. It is, however, but little more than a century since the attention of philosophers was particularly drawn to this subject, and the true foundation of Electricity as a science laid.

136. About the year 1730, Mr. Stephen Grey, of England,

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* This introduction may be omitted, if thought desirable by the instructor.

What is said of the interest which natural phenomena excite? What is said of the forms under which Electricity appears? Has Electricity been regarded with interest in all ages? How recently may the foundation of this as a science be said to date?

commenced the first systematic course of experiments upon Electricity with a rude apparatus consisting mainly of a glass tube and cloth rubber. The result of numerous experiments led Grey to infer that all material bodies belong to one of two classes: *electrics*, or such as are capable of excitation by friction, and *non-electrics*, or those incapable of this. Du Fay, a sagacious French philosopher, repeated these experiments of Grey, and showed that nearly all substances may become electrics under certain conditions. Soon after, he proposed his celebrated theory of *two* electricities,— one produced by the friction of glass, precious stones, etc., which he named *vitreous;* the other from amber and resins, and called by him *resinous* electricity.

No discoveries in science were ever hailed with more delight, or reflected a brighter glory on the discoverer, than those of Dr. Franklin in Electricity. It was about the year 1754 that this profound philosopher published the result of a series of investigations which alone have served to render him immortal, and make his name the pride of every American.

Franklin denied the truth of the theory advanced by Du Fay, and maintained the existence of a *single* fluid which tends to distribute itself equally over all substances. Bodies containing more than their natural share are said to be *positively* charged, or to contain *positive* electricity; those less, *negatively* charged, or to contain *negative* electricity; the former corresponding to the vitreous, and the latter to the resinous electricity of Du Fay. Thus bodies in the former state are disposed to part with their excess of fluid and share it with those about them which are less highly charged; while those

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What is said of Grey and his experiments? What discovery did his experiment lead to? What theory did Du Fay propose? What is said of the discoveries of Franklin in Electricity? What theory did Franklin maintain? When, by Franklin's theory, are bodies said to be positively charged? When negatively charged? What tendency have electricities in bodies differently charged?

in the latter state tend to receive from surrounding objects until the diffusion becomes equal; hence the effort to restore the natural state or equilibrium of the fluid when disturbed, gives rise to the phenomena of the electric spark, or lightning's discharge.

This theory of a single fluid, while it commends itself for its simplicity, is deemed inadequate to explain many of the details of electric phenomena, and the theory of two fluids has accordingly been more generally adopted,— these taking the names positive and negative, as applied by Franklin to the single fluid.

Among the more practical results of Franklin's investigations was the discovery of the identity of lightning and electricity, and the utility of pointed metallic rods for protecting buildings against the dangers of the same. From the period of Franklin's discoveries, Electricity began to assume an important rank among the sciences; and from a fierce and dreaded element, has come to serve as a powerful contributor to the physical and social delights of man.

DESCRIPTION OF ELECTRIC INSTRUMENTS.

137. Within a few years the facilities for illustrating electrical science have greatly improved, and the rude machines of Franklin and Du Fay have been superseded by a far higher and more efficient order of instruments. Some of the more important we shall here briefly describe.

The *Plate Electric Machine*, Fig. 131, may be regarded as the most convenient and efficient instrument for exciting and collecting the electric fluid. A circle of thin plate glass, G, nicely cut and polished, is placed on a steel shaft between two brass shoulders. One of these shoulders is sol-

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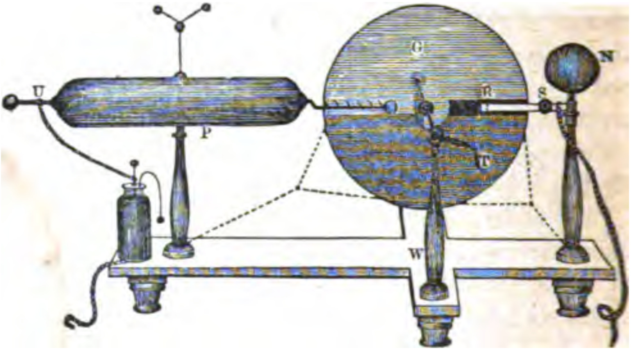
What is said of this theory of a single fluid? State some of the practical results of Franklin's investigations. From the period of Franklin's discoveries what is said of the rank of electricity among the sciences? What is said of the Plate Electric Machine?

dered firmly to the shaft, while the other is movable, and screws up against the glass plate. Two morocco leather-washers, against which these shoulders bind, are stuck firmly on the plate.

This shaft and plate are mounted on wooden posts, **W W**, standing on a beautiful cross basement. Two rubbers, **R**, of buff leather, coated with amalgam, are fastened to brass plates, which are pressed against the glass plate on either side by brass springs, S. These springs are set in a hub placed on the top of the negative post, and held firmly by the negative ball, N, which screws down against it. The prime conductor, **P**, rests on a second insulated glass post; from the end of this, next the plate, extend, in the larger machines, two rows of points, for taking the electricity from the glass surface. From the other end a ball and sliding-rod, U, extend, which in the large machines are movable, and may be drawn out at pleasure. A silk bag, in which the plate revolves, is arranged as seen in the cut.

Fig. 131.



138. *The order of setting up and manner of operating the Plate Machine.*—Place the glass plate evenly against the

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Describe the Plate Electric Machine.

fixed shoulder of the shaft, and screw the other shoulder against it with a moderate force; place the two wooden or shaft posts on the shaft, and lower them together into the holes of the basement, and secure firmly by the nuts and washers underneath. Screw the handle, T, to the shaft; place the rubbers on either side of the glass plate, with the oil-silk flaps downward, and slip the hub on the screw at the top of the negative post, and screw on the negative ball to bind it. Regulate the pressure of the springs by the screw-balls at the side, and let this pressure be light. Attach the rows of points either before or after the prime conductor has been placed on its post, taking care that these stand even, so as not to touch the glass. Place in the opposite end the sliding-rod and ball, and arrange the silk bag to hang free and even when the plate is turned.

139. *Before operating these machines*, see that the shaft-posts rest even on the basement, so as to cause the plate to revolve true and without touching the rows of points. These points should not be allowed to become bent or blunted. Rub the glass posts briskly with an oily silk rag, and also the glass plate, taking care to keep this latter free from any streaks of amalgam which may adhere to its surface.

Whenever the amalgam becomes dry and hard upon the rubbers, remove these, and with a knife ruff this up and soften with tallow, smoothing it again; or, if necessary, spread on more amalgam.

If the floor of the room be dry, let the chain leading from the negative ball extend a good distance along this, or it may connect with a water or gas pipe of the building. Should any points or rough edges be found about the prime conductor, or the jars used for holding the fluid, these should be burnished smooth and covered with a coat of varnish. The escape of the electricity in the dark will point out such defects.*

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* These electric machines should be used with care, and never allowed as mere playthings for boys. A reckless Jehu at the crank may do more injury in five minutes than a careful operator in as many years. With a proper re-

While in use every part of an electric apparatus should be kept free from dust; and never should this be placed in a damp room or exposed to the vapor from unstopped bottles of acids and other liquids.

140. The *Leyden Jar*, Fig. 132. This is used for collecting and holding a quantity of the electric fluid. To charge this *positively*, let the brass ball connect with the prime conductor of the Electric Machine while in action, while the outside coating has a free communication with the earth; a dry and varnished table will not afford this. To discharge the same, apply one of the balls of the *Plain* or *Jointed Dischargers*, Figs. 133, 134, to the outside coating, and bring the other to the knob of the jar.*

Fig. 132.

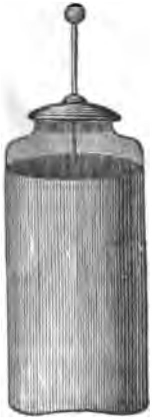


Fig. 133.

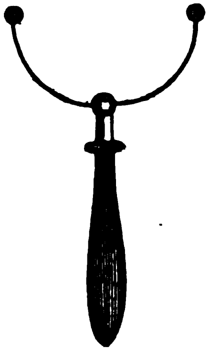
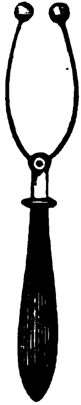


Fig. 134.



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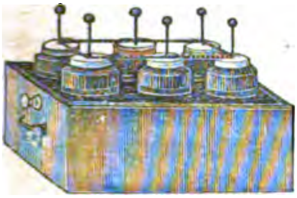
gard to the above directions, the Plate Machine may be made to operate brilliantly during a damp day and in a cold room; although a warm and dry atmosphere is much more favorable.

* The theory of the charge and discharge of the Leyden Jar will be given in a future section.

Use of the Leyden Jar? How charge this positively? Manner of discharge?

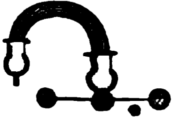
141. The *Electric Battery*, Fig. 135, is a series of Leyden Jars, with their inside coatings connected, and also their outside. To discharge the same, place one ball of the discharger on the brass knob at the side of the case, or the object through which the discharge is to be made, and bring the other to the ball of one of the jars, whereby a communication will be formed between the inside and outside coatings of the jars, and a discharge effected.*

Fig. 135.



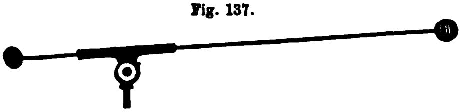
142. *Lane's Discharger*, Fig. 136, may be used for regulating the quantity of electricity to be passed through a body. This, when attached to the prime conductor, or a Leyden Jar, may be effected by sliding the rod with the ball so as to vary the distance according to the degree of the charge to be passed from the jar or conductor. A chain may connect the outside ball with the body through which the fluid is to be passed.

Fig. 136.



The *Directing Rod*, Fig. 137, is a convenient instrument for directing electricity from the prime conductor to jars, etc., arranged upon a table. As it slides in a tube which is jointed, it may be easily directed at pleasure. When in connection with a jar or battery, care should be taken against attempting to adjust it with the hand; as in such a case a severe shock may be received.

Fig. 137.



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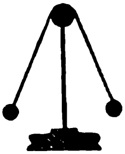
* If any one of these jars be of thin glass, and too highly charged, the fluid may force its way through the side, and so puncture and destroy the jar.

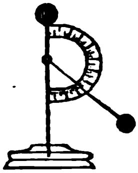
What is the Electric Battery? Manner of discharge? Describe the manner of using Lane's Discharger. For what is the Directing Rod used?

Fig. 138.



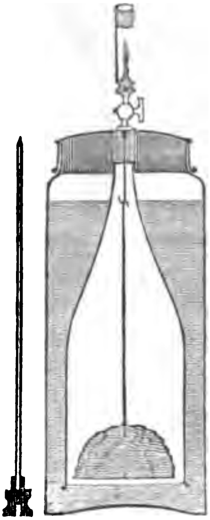
The *Plane and Graduated Pith-Ball Electrometers.* — Figures 138, 139, are used to denote the kind and degree of tension of the electric fluid in Leyden Jars and other electrified objects.

Fig. 139.



143. By means of the *Hydrogen Generator*, Fig. 140, many interesting experiments in the explosion of inflammable gases, by electricity, may be performed. To prepare this for use, fill the jar with a mixture of about one part of sulphuric acid to twelve or sixteen of water, so that when the bell is forced into this and empty, the liquid shall rise nearly to the shoulder of the jar. Before lowering into this, suspend within the bell the copper vessel filled with granulated zinc.* See that all the atmospheric air is expelled from the bell before any flame is brought near the jet attached to the stop-cock. This may be done by opening this and drawing off the gas twice.

Fig. 140.



To fill the Electric Cannon or Gas-Pistol for firing by the electric spark. — Hold these over and just above the stop-cock or long jet attached, and let up the gas; then, before inverting, insert a nicely-fitted cork. The cannon or pistol is now filled with a highly

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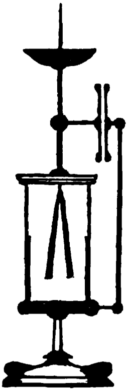
* A roll of sheet zinc may be used with greater convenience and economy. See Fig. 276. A block of zinc is shown in the cut.

Use of the Pith-Ball Electrometers? How is the Hydrogen Generator prepared for use? Describe the process of fitting the Gas-Pistol for exploding by electricity.

explosive mixture of hydrogen gas and atmospheric air. Pure hydrogen will not explode, and in these experiments requires to be mixed with a due proportion of atmospheric air. Should the experiment not succeed, from the too great purity of the hydrogen within the barrel, draw the cork nearly out, and, with the pistol inverted, open end down, blow gently from the mouth for a moment across the end of the barrel, and again replace the cork. This will serve to mix the gases within and render them explosive.*

144. The *Gold-Leaf Electrometer*, Fig. 141, is a delicate instrument for detecting the kind and degree of electricity in bodies. The *metallic cup* is for showing the effect of evaporation on the electric state of bodies. The *point* serves to attract electricity from the atmosphere, and so determine its positive or negative state; while the *condenser* attached to the side detects the presence of slight quantities of the electric fluid, which through its influence show themselves by the divergence or collapse of the gold leaves. This is a serviceable instrument for investigating the electrical state of the atmosphere, and for showing the effects of induction at a distance.

Fig. 141.



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* The platina sponge attached to the stop-cock in the cut is not used in these experiments.

A mixture of two parts of hydrogen and one of oxygen may be used for filling these instruments. This forms a compound much more explosive and sure of ignition, and may be used from a bag in which it has been previously mixed.

Uses of the Gold-Leaf Electrometer?

MECHANICAL ELECTRICITY.

145. Few persons can have failed to notice the singular properties which glass, resins, the fur of animals, and a variety of bodies, acquire when rubbed with dry silk or woollen cloths. If a glass tube, for instance, be rubbed briskly with a silk handkerchief, and then held over small fragments of pith, paper, etc., lying upon a table, these will be seen to fly up and adhere to its surface for a time, and then fall off; and, after a short interval, again fly to the surface of the tube, and so continue to pass and repass between the two surfaces. While in this state, if the tube be held near the face, a tickling sensation, like that from the touch of a cobweb, will be experienced. If the fur of a cat be stroked with a piece of silk, in the dry air of a dark room, flashes of light will be seen, accompanied by a slight crackling sound.

These and a variety of kindred phenomena are attributed to the agency of an exceedingly subtle fluid, or mysterious principle, called *Electricity*, with which all matter seems endowed. Like heat the electric fluid tends to distribute itself equally through all material bodies, and it is only when this equilibrium is disturbed by friction, heat, and other causes, that its effects become visible.

146. *Electricity by Friction.*— Friction is the more common method of exciting this fluid; and by this means *all* bodies may be made to produce it.

Experiment.— Rub the glass tube with the silk handkerchief, as before mentioned; electricity will soon be formed on

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What singular phenomenon does a glass tube present when rubbed with a piece of silk, and then held near small fragments of pith, paper, etc.? Effect of holding such a tube near the face? What is stated in regard to the fur of a cat? To what agency are these and a variety of kindred phenomena attributed? How does electricity distribute itself through bodies? What is the more common method of exciting electricity? State the experiment with the glass tube and metallic rod.

its surface, which will show itself by the emission of slight sparks and the attraction of light substances. Treat a smooth metallic rod in the same manner, and electricity will also be produced, yet without any visible effects. In the former instance the glass, from its non-conducting quality, prevents the escape of the fluid formed on its surface; while, in the latter, the conducting property of the metal allows it freely to escape. Hence, all such bodies as glass, resins, silks and furs, which are capable of retaining the electric fluid, are called *non-conductors;* while those which allow it freely to escape, as the metals, water, etc., are termed *conductors* of electricity.

Experiment a. — Warm a sheet of common writing-paper before the fire, and apply friction with a piece of India rubber, when the paper will soon become so electrified as to adhere to the walls of the room.

The same effect may be produced by the friction of various cloths. Thus, woollen cloths, when brushed in cold and dry weather, often become highly electric, and attract the particles of floating dust.

Experiment b. — Agitate some mercury in a strong glass tube; the friction of this will render the tube electric.

Experiment c. — Blow with a common bellows against the ball of a delicate electrometer; the friction of the air will often excite a sufficient quantity of electricity to become perceptible.

The friction of currents of air against each other and the clouds is thought to be one source of free electricity in the upper regions of the atmosphere.

147. The friction produced by the escape of steam, under a high pressure, from a rough and irregular opening in a steam-

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Why does the glass become excited, while the metal does not? What are such bodies as glass, silks, furs, etc., called, and why? Metals, water, etc.? Give Experiment *a*. What is said of woollen cloths brushed in cold and dry weather? Give Experiment *b*. Give Experiment *c*. What is said of electricity produced by steam?

boiler, is one of the most efficient sources of electricity known.

Thus, by means of a small insulated steam-boiler, three and a half feet long by one and a half in diameter, Mr. Armstrong, of England, was enabled to obtain a spark "fifteen inches in length," and to charge Leyden Jars with a rapidity equalling that of the most powerful plate electric machines.

148. *Electricity is of two kinds.*—We have already, in the Introduction, spoken of the two theories of Electricity proposed by Du Fay and Franklin. We adopt the theory of the former as affording a more satisfactory explanation of many of the details of electric phenomena.

Experiment. — Suspend a pith ball by a long silk thread, and hold near it a glass tube excited as before mentioned. The pith ball will immediately fly to the surface of the tube and adhere for a moment, and then be repelled from it to a considerable distance. Excite now the wax cylinder, Fig. 142, by means of a piece of dry flannel, and hold it toward the pith ball which has been repelled from the glass; it will instantly be drawn to the wax, and then repelled from it, and again attracted by the glass tube, from which it will soon be again driven, and seek the wax cylinder; thus continuing to pass and repass with much energy between the two electrified bodies.

Fig. 142.

149. Thus we see that the electrical states of the glass and the wax in this experiment are widely different,—each attracting what the other repels. The theory of Du Fay in this instance supposes the production of two *opposite electricities*; that, formed upon the surface of the glass being called vitreous or *positive*, and that upon the wax

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Whose theory of electricity is adopted in this work? Give the experiment with the pith ball when acted on by excited cylinders of glass and wax. What is said of the electrical states of the glass and wax in this experiment? What explanation of these phenomena does the theory of Du Fay give?

resinous or *negative* electricity. These two electricities have a strong mutual attraction; and, when separated by friction and other causes, tend to combine again and render each other neutral or latent, which is their natural state.

Thus, in case of the pith ball, when charged with the positive electricity of the glass, it was strongly attracted by the opposite negative electricity of the wax, when it parted with its charge and became negatively electrified; whereupon it was at once attracted by the opposite electricity of the glass, thus serving as the vehicle for conveying to and fro the two fluids, and effecting a neutrality or equilibrium.

These two electricities are always produced simultaneously, the one in the rubber, and the other in the body rubbed. In the example of the glass tube, while it acquired positive electricity from the friction of the silk, the latter became in an equal degree negatively electrified. So of the friction of the wax cylinder; while this became negatively excited by the flannel, the latter acquired a like share of positive electricity.

150. *Theory of the Electric Machine.* — We have already described the construction and mode of operating this instrument, and it remains only to explain briefly the theory of its operation. This acts on the principle of the glass tube, differing only in the greater facilities it affords for creating friction and collecting the electric fluid. As the plate is revolved, friction decomposes the electricities of the rubber, its positive adhering to the plate, while the negative remains behind in the rubber. When the surface of the glass with its charge of positive electricity comes opposite the row of points, the *negative electricity is drawn from the conductor*, and combines with the positive fluid upon the glass, thus leaving the prime conductor

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How are these electricities always produced? What is said of the electrical states of the rubber and the body rubbed? Explain the theory of the action of the Electric Machine.

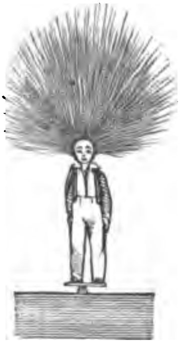
charged with *positive* electricity. If the rubber be insulated, the quantity of electricity is soon exhausted; hence the necessity of the chain for allowing a constant supply to pass up to it from the earth.

To charge a jar positively, we have only to connect the inside coating with the prime conductor, while the outside coating has a free communication with the earth, and work the machine. *To charge a jar negatively*, remove the chain from the rubber, and attach it to the prime conductor, and then bring the knob of the jar to the negative ball, and proceed as before.

151. *Bodies charged with like electricities repel, and with unlike, attract each other.* — *Experiment.* — Place the *Pith-Ball Electrometer*, Fig. 138, on the prime conductor, and work the electric machine. The balls will immediately become charged with the *same* (positive) electricity, and separate as far as possible, as seen in Fig. 131. If, now, the hand or any *negative* body be held towards them, they will be strongly attracted, and follow it as though possessed of intelligence.

Arrange the machine for obtaining *negative* electricity by removing the chain from the negative to the prime conductor, and place the balls on the negative conductor, and proceed as before. The balls will now separate, from being again charged with the *same* (negative) electricity.

Fig. 143.



Experiment a. — The same property of repulsion in matter similarly electrified, may be illustrated by the ridiculous figure of the *Long-haired Man*, Fig. 143. Arrange this as in the last experiment. When electrified the hair stands on end, and each fibre,

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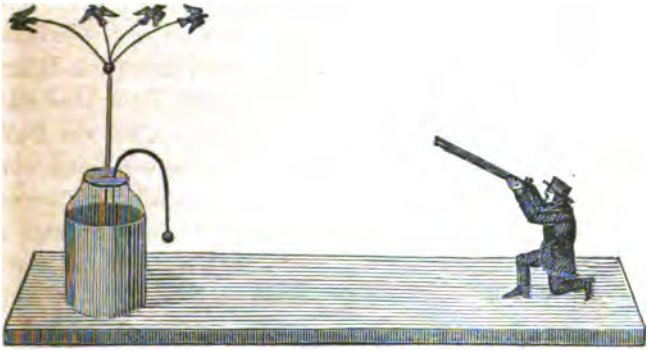
Use of the chain attached to the rubber? How may a Leyden Jar be charged positively? How negatively? State the proposition, section 151. Give the experiment with the Pith-Ball Electrometer. Give the experiment with the Long-haired Man.

as if in a state of repulsion from its neighbor, maintains an isolated and erect position.

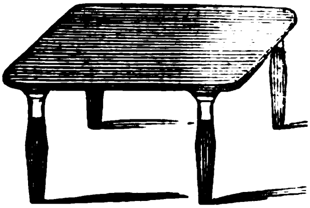
Experiment b. — If some birds cut from light pith, and fastened by fine thread, be placed upon the ball of an *Electrometer Jar*, Fig. 144, and the bent wire be so adjusted as to bring its ball within an inch of the outside coating, upon charging the jar, by connecting with the positive or negative conductors, the birds will gradually rise, attaining a higher elevation as the tension of the electricity increases, until a discharge, accompanied by a loud report, is effected between the ball and outside coating, when the birds will suddenly fall.

Fig. 144.



To render this experiment the more amusing, a fancy sportsman may be arranged, as in the cut, when at each discharge the birds will have the appearance of being *shot down*.

Fig. 145.



Experiment c. — Let a boy with fine and dry hair stand upon the *Insulating Stool*, Fig. 145, and place his hand on the excited prime conductor. He

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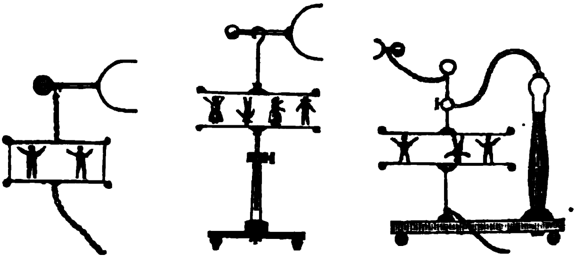
Give the experiment with the Electrified Birds. How may a person become highly charged with electricity? What amusing phenomena may a person thus charged be made to present?

will soon become electrified, causing *his hair to stand erect*, as in Experiment *a*. Sparks may now be taken from the body by any person uninsulated, jars charged, and a variety of amusing experiments performed, as from the prime conductor of the Electric Machine, of which he has indeed become a part. To succeed with this experiment all knives and pointed instruments should be removed from about the person insulated.

152. *Experiment.* — A most amusing illustration of electric attraction and repulsion is shown by the arrangement seen in Fig. 146. Let either of the sets of metallic plates be arranged as seen in the cut, the upper plate connecting with the prime conductor and the lower with the earth. Place between these some fancy pith images, and work the machine so as to regulate the quantity of electricity required; the images will at once commence a lively dance, passing rapidly between the two plates, and conveying back and forth the opposite electricities to restore the equilibrium.*

Fig. 146.



153. *Experiment.* — Let two jars, of equal size, be charged with different electricities, and placed side by side. Suspend

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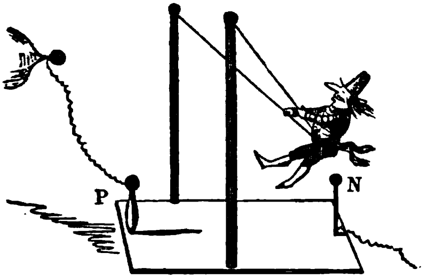
* These plates should hang even, and any rough edges or particles of fibre should be thoroughly removed. A small pin, with the head projecting slightly from the foot, will often give a proper balance and motion to these images when "top-heavy." Three forms are shown in Fig. 146.

Give the experiment with the Dancing Images. What is the experiment with the Electric Spider?

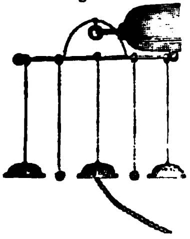
midway between their knobs, by a fine silk thread, a piece of cork or pith, cut in the form of a spider, with threads drawn through it to resemble legs, and the whole colored black. This will vibrate between the two jars, forming an amusing experiment, known as the *Electric Spider;* and, in a short time, the electricities of the two jars will be brought together and rendered neutral.

Fig. 147.



Experiment a. — Let a small *fancy toy*, Fig. 147, made from pith, be so suspended as to swing between the two brass balls, P and N, just grazing upon these. The ball P is placed on an insulated post, and is connected by a chain with the prime conductor, while N communicates with the earth. Work the machine, and the toy will be drawn to P, become positively charged, and then repelled to N, where it will discharge, and then be again attracted; and so pass and repass between the two balls, constituting the *Electric Swing.*

Fig. 148.



Experiment b. — Suspend from the prime conductor the *Electric Bells*, as seen in Fig. 148; the two outer have a metallic communication with the conductor, while the two balls or hammers are insulated from it, as is also the middle bell, which communicates with the earth by a chain. Excite the prime conductor and outer bells positively; the balls will be drawn to these, and, acquiring a charge of positive electricity, will be

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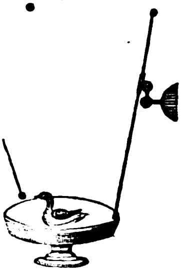
The Electric Swing, Fig. 147? How are the Electric Bells arranged? Give the experiment with these, and the cause of the attraction and repulsion of the balls.

repelled to, and attracted by, the middle or negative bell, where they will discharge and be again attracted to the outer bells, and again repelled; thus passing to and fro, and *ringing out* most forcibly the theory of electric attraction and repulsion.

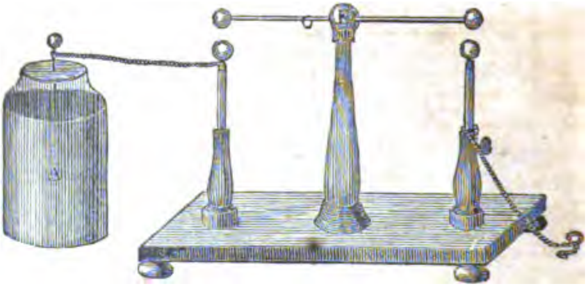
154. *Experiment.* — Place the toy known as the *Electric Swan* in a *glass* basin of water, and connect with the prime conductor as in Fig. 149. Work the machine so as to render the swan and water positively electric. If, now, the finger or any negative body be held towards its beak, *electric attraction* will cause it to swim after and follow the finger, as though possessed of instinct.

Fig. 149.



Experiment a. — The repulsion of like and attraction of opposite electricities is well illustrated by the *Balance Electrometer*, Fig. 150. Balance the rod and balls by means of the movable ring placed on one of the arms. Connect the ball of the insulated post with the Leyden Jar, and charge the same from the prime conductor. The ball of the balance will now be attracted by the positive electricity of that connected with the jar, and, becoming posi-

Fig. 150.

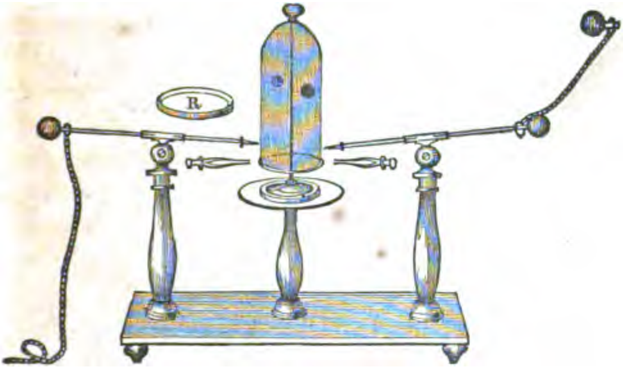


What is the experiment with the Electric Swan? Explain the arrangement of the Balance Electrometer for showing electric attraction and repulsion. Cause of the vibrations of the rod and balls when connected with the charged jar?

tively electrified, the balance will be repelled from this and attracted at the opposite end, where it will deliver its charge, become negative, and be again attracted, and again repelled, thus continuing to vibrate and carry off electricity until the jar is discharged. This experiment may be rendered more amusing by fastening a fancy toy on each arm of the beam, and so illustrating the game of *see-saw.*

Experiment b. — Balance on a point upon the insulating stand of the Universal Discharger, Fig. 151, a *small bell-glass.*

Fig. 151.



Remove the pincers from the conducting-rods, and in their place attach two points; connect one of the rods with the prime conductor, and the other with the earth; bring the points near the sides of the bell, deviating a little upon opposite sides of the diameter of this, and work the machine. The electricity from each point will charge the surface of the glass near it with its own electricity; consequently there will be a repulsion between that of the point and glass, and an attraction between that of the glass and the point upon the opposite side. Acted on by these forces, and being free to move, the bell-glass will commence a rapid revolution, discharging its sides upon

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Explain the theory of the revolution of the bell-glass, as shown in Fig. 151

the opposite points in its revolutions, and thus affording a novel exhibition of electric attractions and repulsions.

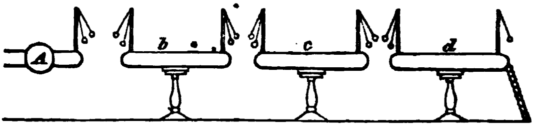
ELECTRIC INDUCTION.

155. A remarkable property of the electric fluid is its power of affecting the electric state of bodies by its mere approach, without any actual communication of itself to those bodies.

Thus, if a glass tube be excited by friction, and held towards some insulated body, to which is attached a delicate electrometer, free electricity will at once become visible in the body, although the tube be held at so great a distance as to preclude the possibility of imparting any of *its* free electricity.

Experiment.—Let three brass cylinders be arranged on glass supports, and provided with pith-ball electrometers placed on wires near their extremities, as seen in Fig. 152. Let *b* be placed in the vicinity of the prime conductor, A. while *d* connects by a chain with the earth. If, now, A be positively excited, it will act to decompose the electricities of *b*, causing its negative to be attracted to the end next to A, while its positive electricity is repelled to the further extremity; thus, the two sets of pith balls attached to the two ends of *b* will diverge from opposite electricities. The positive electricity of *b* will, moreover, decompose in like manner the electricity of *c*, and *c* that of *d*, causing the balls of each to separate as in the case of *b*. The positive electricity of *d*, being driven off to the

Fig. 152.



What remarkable property of the electric fluid is stated in section 155? Experiment with the glass tube and pith balls? Give the experiment with the brass cylinders and sets of pith balls. Explain the theory of these phenomena.

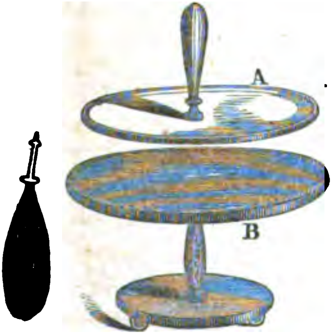
earth, will cause the balls upon its further or positive extremity to diverge less than those at the other extremity. In this experiment no electricity passes from A, but the result is caused by mere induction, as may be proved from the fact that the balls again come together as soon as the excited body is removed.

156. *An electrified body tends always to induce an opposite electrical state in bodies brought near it.* — Thus, in the last experiment, if the *positively* excited glass tube be brought near one end of the cylinder, the natural electricities of this will be decomposed; its negative being attracted to the end next the tube, while its positive will be repelled to that most remote, causing the balls at each end to diverge from different electricities. If, while in this state, the further end of the cylinder be touched by the hand, the positive electricity will escape to the earth, and, upon withdrawing the excited glass tube, the cylinder will be found charged with only negative electricity.

157. Upon this principle of electric induction, may be explained the attraction and repulsion shown in sections 152–3.

The *Electrophorous*, Fig. 153, is an instrument whose action is due to this same cause. A circular metallic basin, B, is filled with melted wax, and cooled, so as to leave a smooth and even surface. This basin or wax disc is then screwed to the top of an insulated glass post. Accompanying this is a circular metallic plate, A, somewhat less in diameter than the disc, and provided with an insulated handle of glass.

Fig. 153.



State the proposition section 156. How illustrated by the previous experiment? Describe the Electrophorous.

Experiment.—Rub the wax disc of the Electrophorous briskly with a warm flannel, or, which is better, whip it with a catskin, and the wax will become negatively electrified. Place now the metallic plate on this, taking it by the glass handle; remove it, and no electrical change is induced; place it again on the wax, and at the same time touch it with the finger, so as to form a communication with the earth; the electricity of the wax will decompose those of the plate, attracting its positive, and repelling its negative, which will escape through the hand into the earth. Now, raise this again by the handle, and hold near the knuckle, when a brilliant spark of *positive* electricity will be received. Place the plate again on the wax disc as before, and remove; another spark may be received; and so the experiment may be repeated any number of times, since the wax loses none of its negative power, but acts only to *induce* a change in the electric condition of the metallic plate.

Experiment a.—With the wax disc excited, as in the last experiment, write on it with the knob of a jar, charged with positive electricity, and then blow upon it a mixture of powdered red lead and sulphur, from a small bag, (Fig. 153), or bellows. The lead powder will adhere to the negatively excited portions of the wax, and the sulphur to the positive, or those portions touched by the knob, clearly defining the course of this by beautifully radiating lines.

The Electrophorous will often retain its action when once charged, for weeks, and is a convenient means of obtaining small quantities of electricity for experiment.

158. *Theory of the Leyden Jar.*—The Leyden Jar is simply a common specie-jar, coated inside and out to the same level, with tin-foil, and provided with a wooden cap, and a ball and chain connecting with the inside coating. Its uses and mode of charge and discharge have been already referred to, § 140; it

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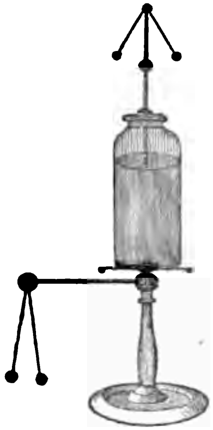
Give the manner of exciting this, and explain the theory of its excitation. State experiment *a*. Describe the Leyden Jar.

now only remains to explain the theory of its operation. This is due to the principle of *induction* just explained.

Experiment. — Place a Leyden Jar upon an *insulated* stand, with a pith-ball electrometer connecting with its inside and outside coatings, as shown in Fig. 154. Connect the inside coating with the prime conductor, and work the machine ; the jar will become but feebly charged, as indicated by the two electrometers. If, now, the knuckle be brought near the outside coating, sparks will be received from this, and the jar become rapidly charged, the inside with positive, and the outside with negative electricity, and both sets of balls will diverge from opposite fluids.

Fig. 154.



In this example the *positive* electricity, as it enters the inside, acts by *induction*, through the non-conducting glass, to *repel the same* from the outside of the jar, and *attract its opposite negative* electricity; but, while insulated, the escape of the positive fluid from the outside is prevented, which precludes the entry of the same into the inside. Hence the reason of the necessity of a free communication between the outside coating and the earth, during the act of charging a Leyden Jar or battery.

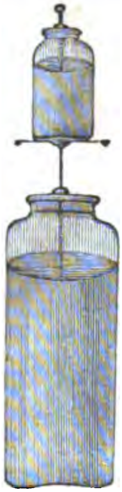
159. Glass, resins, air, and all kindred insulating media which resist the passage of the electric fluid, but through which this may exert its inductive power, are called *dielectrics*. Through these, electricity is supposed to act by a *polarization* of their particles; each molecule of the glass, etc., being thrown into opposite electrical states, as in the case of the cylinders, Fig.

State the experiment with the Leyden Jar placed upon an insulated stand. What will be necessary to enable the jar thus placed to become fully charged? Give the explanation of this phenomena. What are dielectrics? How is electricity supposed to act through such bodies?

152, and thus, by a series of attractions and repulsions, an influence traverses the intervening medium, which produces its decomposing effects beyond.

160. *The force of induction diminishes rapidly as we recede from the exciting cause;* hence, the thinner the glass of the Leyden Jar, and the nearer the two fluids are brought, the more intense will become the electric charge. If, however, the glass of the Leyden Jar, for instance, be too thin, the tension of the fluids may be so great as to overcome this resistance, and so unite by forcing a passage through the glass, thus puncturing and destroying the jar.

Fig. 155.



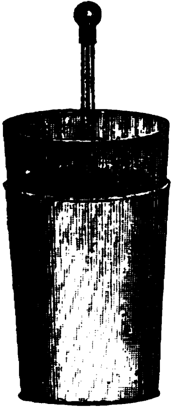
Experiment. — Arrange two Leyden Jars as in Fig. 155; connect the ball of the upper with the prime conductor, and charge the inside positively; this will repel the same fluid from its outside into the jar below, when both will be found to be positively electrified. By arranging a series of jars upon an insulated surface, and connecting the outside coating of the one in communication with the prime conductor with the inside of the next, and so on, the whole may be charged, each from the electricity driven off from the outside coating of its preceding neighbor; the charges, however, becoming more feeble according to the distance from the prime source of induction.

Electricity resides mainly on the surface of the glass in the Leyden Jar, while the metallic coatings serve only as conductors of it. This may be satisfactorily shown by a jar with *movable coatings*, as seen in Fig. 156.

What is said of the force of induction as we recede from the exciting cause? What is the experiment with two jars seen in Fig. 155? What is said of the manner of charging a series of jars from each other? In the Leyden Jar where does the electricity mainly reside?

Experiment a.—Apply the ball to the prime conductor, and charge the jar; lift out the inside coating by the glass tube, and hold it suspended, avoiding the metallic ball; free the outside vessel or coating from the glass, by inverting on the table; place the smaller within the larger coating, and apply the discharger. No electricity will be found on these metallic surfaces. Now, slip the outside coating over the glass again, taking care not to touch with the hand the surface of the glass, and replace the inside one as before. If the discharger be now applied, a vivid flash will pass between the two coatings, showing that the electric fluid remained *on the surface of the glass*, while the metallic coatings served merely as conductors for the same.

Fig. 156.



161. *The tension of electricity varies inversely as the surface over which it is distributed.*

Experiment.—Let two tin cylinders, say three by eight inches, fit one within the other, the inner being provided with an insulated handle, and attach a delicate pith-ball electrometer to the outer one; place the whole on an insulated stand, and charge with electricity. The pith balls will separate and show the degree of tension of the electricity. Now raise the inside cylinder slowly by the insulating handle, the balls will gradually fall, showing a diminution of the electric tension, as the fluid becomes distributed over a greater surface; depress the cylinder, and the balls will again rise. After a jar or battery has been charged for some time, and then discharged, it will often spontaneously recover its charge to a considerable extent, giving rise to what is known as the *residual charge*.* This, according to Faraday, is caused by the electric fluid which is forced into the glass among its particles by the tension of the electricity on its surface, and which returns slowly to the surface as the external force is removed by a discharge. From this cause an ordinary battery will sometimes accumulate sufficient electricity, after a discharge, to give a smart shock.

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* Whenever a discharge is made through a body, from one conductor tc

How may this be proved by means of the movable-coating jar, Fig. 156? How does the tension of electricity vary? How may this be proved?

LUMINOSITY OF THE ELECTRIC SPARK.

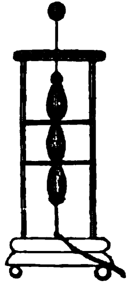
162. *Whenever any considerable quantity of electricity is passed through a medium which resists its passage, light and heat are produced.* — These are caused by the sudden compression of the air or other medium before the electric fluid in its rapid passage, whereby latent heat becomes sensible, accompanied by light. The *color* and *course* of the electric park vary with the media through which, and the conductrs between which, it is passed. The following experiments equire a dark room.

Experiment. — Unscrew one of the balls from the discharger, Fig. 133, and substitute a ball of ivory; place the other metallic ball against the outside coating of a charged jar, and bring the ivory ball towards the knob of the same; the light from the electric discharge, between the knob and the ivory, will be of a *deep crimson.* Substitute in place of the ivory ball a lump of sugar, when the color of the spark will be *white*, and the sugar will remain luminous for some time. Fluor spar will give a *green* light.

another, a chain or wire should lead from the further conductor to the outside of the jar. Unless this be observed when the jar is grasped by the hand, the body of the operator forms a portion of the electric communication between the two coatings, and a severe shock may be received.

What is meant by the residual charge? How is this, according to Faraday, caused? Under what circumstances are light and heat produced by electricity? How are these caused? How do the color and cause of the electric spark vary? Experiments showing this?

Fig. 157.



Experiment a.— Place some *eggs* in a stand, as seen in Fig. 157, connecting the bottom of the series with the earth, while the ball at the top is made to communicate with the prime conductor or a charged jar. The passage of the electricity through these will so powerfully illuminate each, as to show distinctly the whole interior structure of each egg.

163. If letters and other characters be formed by sticking with varnish small spots of tin foil on some insulating surface, as oiled silk or glass, so that each spot shall be separate from its neighbors, and an electric spark be passed through these, the instantaneous passage of the fluid will render the whole word or other figure beautifully luminous.

Fig. 158.

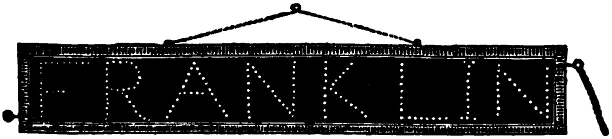
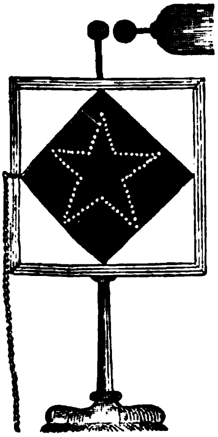


Fig. 159.



Experiment. — Connect one end of the *Luminous Frame*, Fig. 158, with the floor and earth; bring the ball at the other end to the prime conductor, or, which is better, to the outer ball of Lane's Discharger, properly adjusted, when the whole word will appear as above stated. A pane of glass set in a frame, and spotted to represent a *profile* or *star*, Fig. 159, presents, also, a splendid illumination when the electric spark is sent over it.

Give the experiment with the eggs. How may letters, figures, etc., be rendered luminous by electricity?

Fig. 160.

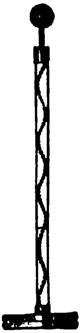
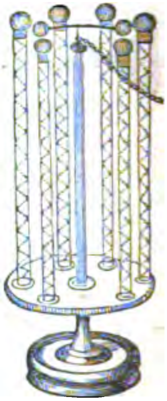
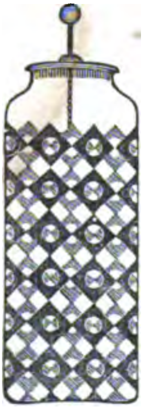


Fig. 161.



Experiment a.—Fig. 160 shows a glass tube spotted on the *inside in a spiral form.* Present the ball of this to the excited prime conductor, as in the last experiment, holding the bottom by the hand, or connecting its brass cap with the earth by a chain, and brilliant spirals of electric light will flash down the tube as the machine is worked. A string or necklace, formed by sewing together spots of tin foil with silk thread, may be rendered luminous in the same manner. Fig. 161 shows several of these tubes arranged on a circular stand, and illuminated by the revolution of two balls, attached to a wire lever, which revolves on a point upon the top of an insulated support. The wire and balls connect with the prime conductor, and, as they revolve, discharge the electricity from this, down the tubes, forming a most brilliant experiment.

Fig. 162.



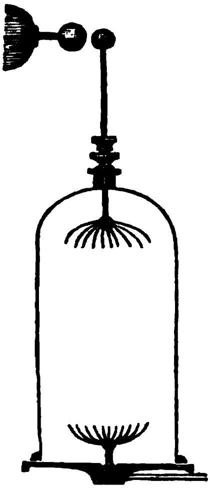
Experiment b.—Connect the knob of the luminous or *Diamond Jar*, Fig. 162, with the excited prime conductor, and make a free communication between the outside coating and the earth. The electricity, as it distributes itself over the inside of the jar, will present one series of illuminations, and, as the same is repelled from the outside, another; and, thus constantly leaping across the insulated spaces, will render the whole jar luminous by constant flashes of light.

164. *Electricity passes with increased facility through rarefied air*, the light diminishing in brilliancy as the rarefaction approaches a vacuum.

Give experiment *a*, with the spotted tube. What is said of the passage of electricity through rarefied air? Give the experiment with the Diamond Jar.

Experiment.— Screw to the plate of the air-pump, and also to the end of the sliding-rod, sets of metallic-points, as seen in Fig. 163. Connect with the prime conductor, work the Electric Machine, and at the same time exhaust the bell-glass. As the air in this becomes more rare, the electricity will pass more freely between the sets of points, exhibiting a most singular luminosity, resembling the Aurora.

Fig. 163.



Experiment a.— Remove the sets of points in the last experiment; screw a ball to the lower end of the sliding-rod; place under the receiver a Leyden Jar; bring the ball of the rod near that of the jar, and connect with the prime conductor, as in the last experiment. Charge the jar in this position, and then exhaust the receiver. As the rarefaction proceeds, a luminous current of electricity will flow over the jar from the positive to the negative side, until the equilibrium is restored.

Experiment b. — Place two metallic points within the long *Guinea and Feather Tube* (see Pneumatics, Fig. 50), and screw this by the stop-cock to the plate of the air-pump. Connect the ball of the upper end with the prime conductor, and, when the tube is well exhausted, work the machine. The electricity will now pass freely through the whole length between the two points, presenting streamers of light, strikingly similar in appearance to the *Aurora Borealis.*

Experiment c. — If, instead of the points in the last experiment, two small balls be substituted, and, when the tube is well-

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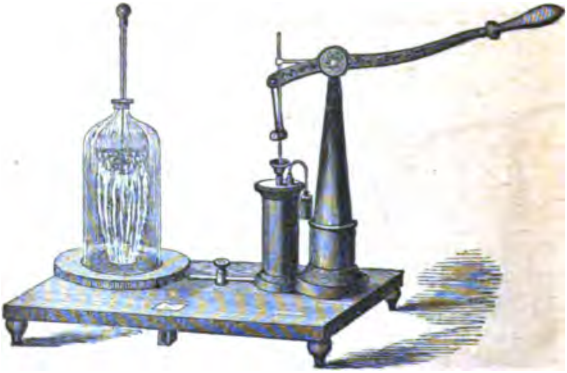
Give the experiment with the sets of luminous points. Give Experiment *a*. Give the experiment for showing the luminosity by electricity by means of the Guinea and Feather Tube, Fig. 50. What does the light in this experiment strikingly resemble?

nigh exhausted, a charge from a highly electrified battery be passed, the electricity will descend in a brilliant ball of white light, forming the beautiful experiment known as the *falling star*.

A beautiful modification of these experiments is shown by an apparatus, known as the *Abbe Nollet's Globe*, Fig. 164. A glass globe with a long neck passing up through the opening of a glass receiver, is sealed to this, so as to be air-tight. Upon the top of this neck is a movable cap and ball, with a chain attached, and leading down into the globe.

Fig. 164.



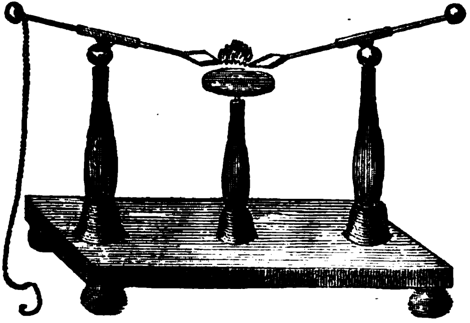
Experiment d.—Place the receiver on the plate of the air-pump, raise the cap and ball, and fill the globe with water as high as indicated by the cut. Connect the ball with the excited prime conductor, and at the same time exhaust the receiver. As the rarefaction of the air increases, streams of electric light will shoot across from the glass to the brass plate, constantly varying in color and form, with the degree of the exhaustion, from the white spark to the purple brush.

Describe the Abbe Nollet's Globe. What is the experiment with the Abbe Nollet's Globe?

COMBUSTION BY THE ELECTRIC SPARK.

165. As we have already remarked, *light* and *heat* are the results of the electric spark in its passage through such media as air and the gases, which offer a resistance to its course. These vary with the quantity of the fluid and the density of the medium through which it moves. Even with the limited quantity which may be collected in a Leyden Jar, or ordinary battery, the calorific effects of electricity may be shown by a great variety of curious and striking illustrations. For many of these, the Universal Discharger, Fig. 165, is a convenient instrument.

Fig. 165.



Experiment.— Place on the insulating glass stand of the Universal Discharger a ball of cotton filled with finely powdered resin. Bring to each side of this the balls of the sliding-rods; connect one of the rods with the outside coating of a charged jar by a chain, and on the other place one ball of the discharger, Fig. 165, and bring the other ball quickly to the knob of the jar; the passage of the electricity through the cotton will cause it to be inflamed. The same may be shown by placing the cotton on one of the balls of the discharger, Fig. 133, and bringing near the knob of the charged jar.

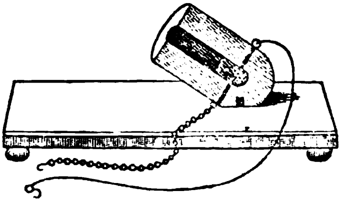
Experiment a. — Reverse the sliding-rods of the last exper-

How do the light and heat produced by electricity vary? Give the experiment for inflaming cotton by electricity. What is the experiment with gun powder?

iment, so as to bring the points within a half an inch of each other, while resting on the glass stand. Pour some fine gunpowder between these, and discharge as in the previous experiment; the powder will be scattered in every direction, but not ignited. Cover the points with this as before, and let a *wet string* or body of water form a part of the connection between the sliding-rod and jar; discharge again, and the powder will be readily exploded. This is probably occasioned by the surprising velocity with which the fluid travels (576,000 miles per second), not allowing, in the former case, sufficient time to produce its calorific effects, and requiring for this a less perfect conductor, as water.

166. *Experiment.*— The *Powder Bomb*, Fig. 166, exhibits a more striking form of the same experiment. Pour into this a thimble-charger full of fine powder; wet the string attached to one of its wires, and hook it on to one arm of the discharger; let a chain lead from the other wire to the outside of a charged jar, and bring the other arm of the discharger to the knob of the same. The passage of the electric fluid across an interruption of the two wires will ignite the powder with a loud report.* Fig. 166 shows a sectional view of this instrument.

Fig. 166.



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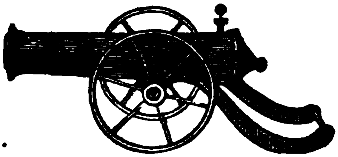
* In all experiments for igniting gunpowder by electricity, a small glass tube filled with water forms the best connection. This may be about ten inches long, having two wires entering its ends, through tight stoppers, smeared over upon the outside with sealing-wax. These wires should approach each other in the tube, so as to leave about four inches of water between their ends.

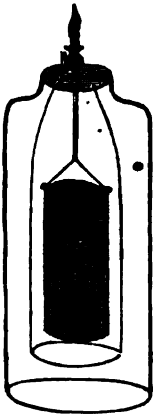
Why will this not be ignited by the electric spark when it is placed between good metallic conductors? Give the experiment with the Powder Bomb

Fig. 167.



Experiment a.— Fill the *Electric Cannon*, Fig. 167, with a mixture of hydrogen gas and common air, by means of the Gas Generator, Fig. 168. Insert in this cannon a tight cork, and let a chain connect it with the outside of a charged jar. Pass the electricity down the insulated wire attached to the small ball of the priming-hole. As it passes from the end of this wire to the side of the cannon, through the gas, this will explode, and the cork be forcibly expelled with a loud report. This cannon may be charged with powder also, and fired, as in the previous experiment.

Fig. 168.



Experiment b. — A highly amusing form of the last two experiments, showing the igniting power of the electric fluid at a distance, may be exhibited as follows: Let two small wires lead, unobserved, from the lecturer's table, along a side of the room, to a remote corner. Place there a loaded cannon, and let a glass tube of water form a portion of the connection, as remarked above. Place on the priming-hole a small ivory or wood cup, opening into the cannon, and provided with two wires with blunt ends, about an eighth of an inch separate. Connect one of these with the positive wire leading from the glass tube, and the other with the other wire, and fill the cup with fine powder. These may be arranged before the audience assemble; and, during the lecture, a jar, placed upon the table before the lecturer, may be discharged through these wires, causing the cannon to explode, to the great astonishment of the unsuspecting company.

What experiment with the Electric Cannon?

A strong tin canister may be filled with explosive gas, and fired in the same unexpected manner; the use of the glass tube, however, being unnecessary for this. The Galvanic Pistol, Fig. 191, Galvanic Electricity, may be arranged for firing by electricity.

Fig. 169.

167. *Experiment.*— Pour into the *EtherSpoon*, Fig. 169, sufficient sulphuric ether, or strong alcohol, to cover its bottom. Hold this under a ball connected with the excited prime conductor, and let an electric spark pass into it, when *the liquid will burst into a flame ;* a common silver spoon will answer. A person electrically charged, as in Experiment *c*, § 151, may fire this by bringing over and near the liquid his finger, so as to allow of the passage of a spark.

Experiment a.— Arrange two or three feet of iron chain in separate coils upon a sheet of white writing-paper, and pass through this a charge from about eight square feet of coated surface; the portions of the paper upon which the chain rests will be scorched, and, if the charge be sufficiently great, even *burned through*, by the heat of the electric fluid.

Experiment b. — Place the hair-spring of a watch between the pincers of the Universal Discharger, and discharge through this a charge, as in the last experiment, when *it will be literally consumed.* Thus, lightning often melts metallic conductors, which are too small to conduct it freely.

168. *Mechanical Effects of Electricity.*— These effects are often seen in the passage of the fluid through imperfect conductors, such being rent asunder with the greatest violence, without showing any signs of heat, as in the previous experiments.

Experiment.— Suspend a thick card between the balls of the Universal Discharger; bring these directly opposite and near the

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How may ether or alcohol be fired by the electric spark? Give Experiment *a*. Experiment with a fine watch-spring? When are the mechanical effects of electricity exhibited?

same; pass a charge from a battery, as in Experiment §165; the electricity will puncture the card without moving it, so great is its velocity. A peculiar hole is thus formed, with *a burr projecting out both ways*, as though the fluid had proceeded from the centre of the card. This experiment is regarded by many as one of the proofs of the existence of *two fluids*, which, in a discharge between conducting bodies, proceed in opposite directions. A still more convincing proof of this is given by

Experiment a. — Color a card with vermilion, and place it between the points of the Universal Discharger, so that one of these shall be about half an inch above the other, and discharge the battery as in the last experiment. The card will be perforated at the point connected with the *negative* earth, while a black line of reduced mercury will trace the path of the electricity along the surface of the card between the two points. This curious effect is attributed to the greater rapidity with which the positive fluid passes through air; for, if this experiment be performed *in vacuo*, the perforation will always take place at a point *intermediate* between the two metallic points.*

Experiment b. — Drill two holes in the ends of a piece of dry wood, half an inch long, and a quarter of an inch thick; insert two wires in these, so that their ends shall be rather less than a quarter of an inch apart; pass the charge of a large battery through these wires, and the wood will be split with violence. The same may be done with stones.

Experiment c. — Suspend in a common wine-glass, nearly filled with water, two wires, tipped with metallic balls, so that these shall be about half an inch apart. Send through these wires a charge from a four-quart jar or small battery; the

* Bird.

Experiment with the card placed between the two balls of the Universal Discharger? How is this experiment supposed to prove the existence of twc electric fluids? State Experiment *a*. To what are the curious effects seen in this experiment attributed? State the experiment where an electric discharge is made through a wine-glass filled with water.

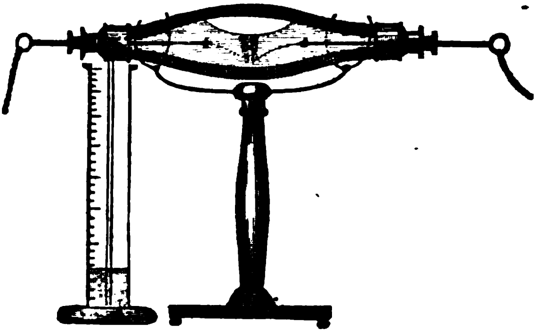
passage of the electricity through the water between the balls will cause the glass to be shivered.

Large rocks are sometimes removed by drilling a hole and inserting the lower end of a metallic rod which shall attract the lightning. This, passing down the rod, enters the rock, scattering it with a force far superior to gunpowder.

169. *Decomposition by Electricity.*—That form of electricity most effective in causing the decomposition of compound substances is produced by chemical action, and known as *Gálvanism.* This is characterized by a far lower tension, but a vastly greater quantity, than common frictional or static electricity. The decomposition of a liquid, for instance, depends on the *quantity* of electricity passed through it; hence, for rapid decomposition, the Galvanic Battery is commonly employed. The same may, however, be effected to a certain extent by the electricity from friction.

Experiment.—Remove one of the screws and rod from the end of the thick glass receiver of the *Decomposing Apparatus*, Fig. 170, and fill this with water. Replace, and bring the two balls near each other; pass repeated charges from a large battery through the water between the balls; the gases oxygen and hydrogen, the elements of which the water is composed,

Fig. 170.

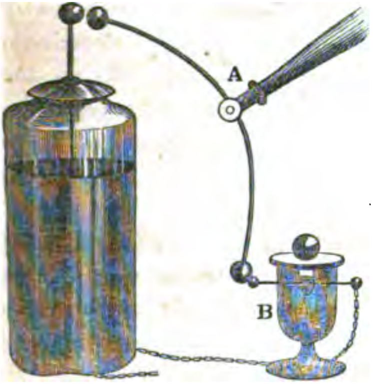


How are large rocks sometimes rent asunder by the aid of electricity? What form of electricity is most effective in producing the decomposition of compound substances? Can such decomposition be effected by common frictional electricity? Give the experiment for illustrating this.

will be separated and collected in the upper part of the receiver. If a sufficient number of discharges be made, these gases will be produced in such quantities as to fill the receiver down to the balls, when they will be ignited by the electric spark, and reünite to form water again, this rising and filling the receiver once more; thus showing *the decomposition and recomposition of water by the electric spark.*

Experiment a. — Drop into the *Electric Mortar*, B, Fig. 171, sufficient oil or water, to cover the ends of the conducting-wires. Place the ball, over the hole, to which it is nicely fitted, and pass the electricity from a charged jar, as shown in the cut. As it passes between the wires, through the liquid, *this will be decomposed*, and form gases, which will suddenly expand, so as to throw the ball several feet into the air. If repeated discharges from an electric battery be made through a portion of confined air, the two gases, oxygen and nitrogen, which are mechanically mixed to form this, will become chemically united by the electricity, and form an exceedingly strong acid, known as *aqua fortis.* Thus, lightning acts to coagulate or sour milk and other albuminous liquids, by forming in the atmosphere, during a thunder-shower, this corrosive acid.

Fig. 171.



170. *Electricity is strongly induced about metallic points*, which attract and discharge it with far greater facility than blunted surfaces.

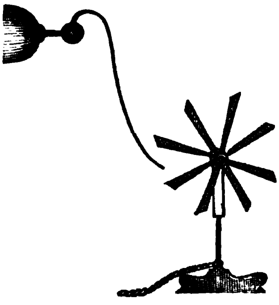
Give the experiment with the Electric Mortar. The effect of repeated discharges of electricity through a portion of confined air? Cause of the souring of milk, etc., after a thunder-storm? Effect of metallic points in reference to the electric fluid?

Experiment. — Place a pith-ball electrometer on the knob of a jar, and charge positively, or on the prime conductor. If, now, a metallic ball be held toward this, it will have but little influence in removing its positive electricity, as shown by the very gradual descent of the pith-balls; but remove this, and present instead a pointed wire, when the electric fluid will be rapidly withdrawn, and the balls quickly fall. If in a darkened room, the point held toward a positively charged body, as the Leyden Jar, in this instance, will show a *star* of electric light, and, if presented to a negatively charged body, a ***brush*** of light.

It is thus, that, during the passage of a highly electrified cloud, spires of churches, masts of vessels, and other pointed objects, are often, during the night-time, tipped with light, the electricity passing between the charged cloud and pointed object, the same as between the prime conductor and metallic point. Such a light is known among sailors as Castor and Pollux, and is a cause of dread, as oftentimes immediately preceding a discharge of lightning.

171. The *Electric Aura* is a current produced in the air by the escape of electricity from a point. This is often sufficient to cause small wheels to revolve, and even to move delicate machinery.

Fig. 172.

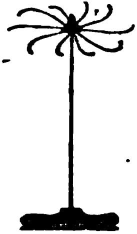


Experiment. — Place a pointed bent wire in the ball of the prime conductor, and bring near it a delicate *float-wheel*, as seen in Fig. 172. Work the machine, and the escape of the electricity from this will cause the wheel to revolve rapidly.

How shown by a metallic point placed on the prime conductor? When will the illumination at the point be a star? When a brush of light? What is said in regard to the phenomenon occasionally exhibited during the night-time by pointed objects when electrified clouds are passing? What are these lights called by sailors? What is the Electric Aura? How shown by the float-wheel and point?

The *reäction* of the current thus formed may be well illustrated by the following:

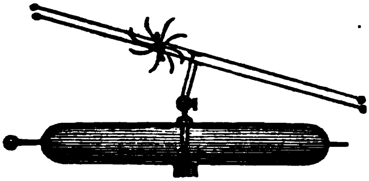
Fig. 173.



Experiment a. — Stand the pointed wire, Fig. 173, with its wheel of S's, on the prime conductor, and excite the machine. The escape of electricity will produce a reäcting current, which will cause this wheel to revolve rapidly, and in the dark these points will present a beautiful luminous circle.

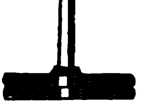
Experiment b. — Provide such a wheel with an axis, and let the ends of this rest on an *inclined plane* of wires, as shown in Fig. 174. Connect with the excited prime conductor; the reäction against the points will cause the wheel to *roll up the inclined plane.*

Fig. 174.



Experiment c.—A highly amusing illustration of *electrical reäction*, may be shown by the *Electric Season-Machine*, Fig. 175. Here an arrangement representing the sun, earth, and moon, is balanced on a point upon the top of an insulating post. From each of these bodies and the main wire project points. When electrified from contact with the prime conductor, the escape of the fluid from the points will cause a reäction sufficient to make both sets of wires, with their balls, revolve somewhat after the astronomical order.

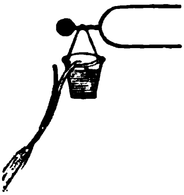
Fig. 175.



How may the reäction of the air on a current of electricity escaping from points be shown? Explain the operation of the Electric Season Machine.

Electricity is an efficient agent in promoting *evaporation*, which it does by its force of self-repulsion, driving asunder the particles of liquid, and thus rendering them minute and volatile. This may be well illustrated by an arrangement seen in Fig. 176.

Fig. 176.

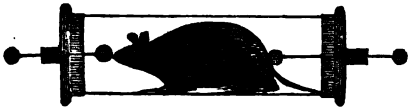


Experiment d.—Suspend from the prime conductor a small metallic bucket of water; place in this a siphon, and cause it to flow, and work the machine. The electrified water, instead of falling in a stream, will be *dispersed in a fine mist.*

172. *Effects of Electricity on the Animal System.*—Whenever the body of an animal is made a part of the electrical circuit, an involuntary and painful muscular contraction is experienced; and, if the charge sent through this be sufficiently great, instant death is the result. If a powerful charge be passed through a portion of the body, as a single limb, for instance, the sensibility of this may be destroyed. Thus, Van Marum found that the eel, an animal exceedingly tenacious of life, was instantly killed by a shock passed through the whole body; and when passed through only a portion of this, that portion was destroyed.

Experiment.—Place any animal, as a rat, for instance, in the glass tube, Fig. 177, and discharge through it a large jar or battery—instant death will be the result.*

Fig. 177.



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*The bodies of animals killed by lightning are found to undergo rapid putrefaction, and it is a remarkable circumstance that after death the blood does not coagulate.

What relations is electricity supposed to sustain to evaporation? How does it promote evaporation? Give the experiment with the small bucket and siphon. State the effects of electricity on the animal system. Case of the eel.

Experiment a.—Let any number of persons join hands; charge a quart jar, and while the one at one end clasps the outside of the jar, let the one at the other end complete the electric circuit, by touching its knob, when the whole will experience a smart shock in the arms at the same instant. Thus, Abbe Nollet passed an electric charge through a circuit of fifty-four hundred persons, when a convulsive shriek was given at both ends at the same instant.

Experiment b.—An amusing illustration of the same principle may be shown as follows: Coat a large pane of glass with tin foil to within about two and a half inches of its edge, on both sides. This may be set in a wood frame, similar to Fig. 159; now connect the coating of the under side, by a narrow strip of tin foil and a chain, with the earth; place upon the other side *a piece of coin*, and connect with the excited prime conductor; the glass will become charged like a Leyden Jar, and, if attempts be made to remove the coin with the fingers, the person, who will form a portion of the electric circuit, will receive a painful shock, causing a failure in the attempt. This forms the well known experiment with the *Miser's Plate.*

173. The virtues of electricity as a *medical agent* were, in the early stages of the science, greatly exaggerated. Electrified medicines, purporting to effect remarkable cures, were dealt to the patient in medicated tubes, and a variety of gross imposition was for a time practised by learned pretenders. Such a course soon brought electricity, as a healing agent, into disrepute, and caused it to be well-nigh discarded in medical practice. Its efficiency, however, in cases of paralysis and imperfect circu-

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How may a company of persons be arranged for receiving the shock from a Leyden Jar? Give the experiment with the Miser's Plate. How were the virtues of electricity, as a medical agent, regarded in the early stages of electrical science? In what diseases of the body is it beneficial? What kind of electricity is usually employed for medical purposes?

lation, is now too well known to admit of a doubt.* The kind of electricity more generally administered is that of the galvanic battery. The form of instruments, and mode of application to the patient, will be found fully described in works specially devoted to this subject.

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* Ferguson, in his Introduction to Electricity, published in 1778, relates the following among many other remarkable cures through the agency of electricity. We give them in his own words. "A young man, who had well-nigh lost his hearing, so that those who spoke to him were obliged to speak very loud, came twice to be electrified. I only drew sparks from his ears, and at the second time he heard very well, and continued to do so afterwards.

"I was once, at Bristol, seized with a sore throat, so that I could not swallow. Mr. Adlam, of that city, who is a fine electrician, came and drew many electric sparks from my throat, and, in about half an hour after, he did the same again. He staid with me about an hour longer, and before he went away I could eat and drink without pain, and had no return of the disorder. I have relieved several persons in such cases, but never in so short a time. I have often drawn sparks from chilblains, and always found they were cured thereby.

"One time my wife happened to scald her wrist by boiling water. I set her upon the insulating stand directly, and took sparks from the wrist. In a short time I found the redness of the skin begin to disappear, and she felt immediate relief. I repeated the operation, which entirely cured her, and there was not the least blister left on the skin."

ATMOSPHERIC ELECTRICITY.

174. THE atmosphere is always found charged, to a greater or less extent, with electricity. This varies, in kind and degree, with the causes which produce it. As we ascend to the more elevated regions, the quantity of electricity present in the atmosphere increases; and, in clear and settled weather. this is found to be positive in regard to the earth. In changeable weather, and especially during a thunder-storm, the atmosphere is sometimes positive and sometimes negative, often changing its electric state quite suddenly. The presence of electricity in the atmosphere may be readily shown by extending into it a pointed metallic rod, insulated, to the bottom of which is attached a delicate electrometer. Even in clear weather sufficient electricity may be attracted by this to cause the leaves of the electrometer to diverge, and, during a thunder-storm, vivid sparks can often be taken, sufficient to charge jars and electric batteries, and perform all the results of a common electric machine.

175. We have already, in the introduction, alluded to the grand discovery by Franklin of the identity of lightning and common machine electricity. This he proved, most conclusively, by means of a kite, which he elevated during the passage of a thunder-cloud, when the electricity or lightning from this cloud passed down the wet string, and was collected in jars, like that from an ordinary electric machine.

176. By means of an extended and connected series of pointed wires, erected on trees and elevated objects, a prodigious quantity of electricity may be collected for experiment; far

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What is said of the electricity present in the atmosphere? What is said of the electric state of the atmosphere in changeable weather, and during thunder-storms? How may the presence of electricity in the atmosphere be detected? Experiment of Franklin for proving the identity of lightning and electricity? How may large quantities of electricity be collected from the atmosphere?

exceeding that produced from any artificial source. Thus, Mr. Crosse, a celebrated English electrician, was enabled, with one third of a mile of wire, to collect from the atmosphere, when in a highly electrified state, sufficient electricity to charge a huge battery, of seventy-three square feet of coated surface, "*twenty times in a minute*, accompanied by reports as loud as a cannon." And with a large kite, having a string inwoven with fine wire, and elevated to the height of five hundred and fifty feet, M. de Romas, a French philosopher, obtained from the conductor to which the string was attached during the passing of a thunder-cloud, "balls of electric fire ten feet in length, and an inch in diameter."

177. *Evaporation* is regarded as the prime agent employed in distributing electricity through the upper regions of the atmosphere. The earth is the great reservoir for the electric fluid; from this the vapors, which are constantly rising, bear it aloft, these being rendered volatile by the self-repellant properties of the electricity which they contain. When this watery vapor reaches an elevation where the condensing power of cold is sufficient to overcome the repulsive force of the electricity, clouds are formed, and the electric fluid, like latent heat, becomes sensible in the condensed vapor of the cloud.

178. *Thunder-Clouds*, of all aerial bodies, exhibit the highest degrees of electric excitement. These are usually formed, during the heat of summer days, from the rapid condensation of vapor with which the atmosphere is then saturated. As they increase in density and extent, the tension of their free electricity becomes greater, until soon this reaches such a degree as to overcome the resistance of the non-conducting air, when a discharge of lightning takes place, either towards some neighboring cloud less electrified, or the earth.

Describe the apparatus of Mr. Crosse for collecting electricity from the atmosphere. Give the result of M. de Romas' experiment. What is said of the agency of electricity in evaporation? How does electricity aid evaporation? When are thunder-clouds usually formed? How is lightning evolved from these, and upon what does it discharge itself?

Isolated clouds, which form rapidly from vapor condensed by the meeting of warm and cold currents of air, usually present the most terrific electric phenomena. Such are usually marked by a violent commotion, a flying and whirling of detached fragments about the denser portions, a black and threatening appearance, and, as they increase in size, by frequent discharges of lightning, followed by terrific peals of thunder and torrents of rain.

179. The thunder-cloud may be regarded as a huge electric battery suspended in the heavens, and insulated by the surrounding air. In this prodigious quantities of the electric fluid accumulate, and, when overcharged, discharge, like the ordinary battery, upon the nearest object.* These clouds are often negative in regard to each other and the earth; in such a case, the lightning is seen to leap from one to the other, until the equilibrium between them is restored. Occasionally flashes of lightning are seen to pass between two clouds, separated by a considerable distance, and the earth, at the same moment. In such instances, the clouds are supposed to be in widely different electric states, but too far separated to allow of a direct passage of the fluid, which takes a circuitous route, passing from the positively electrified cloud to the earth, and

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* The quantity of the fluid in a discharge of lightning varies with the dimensions of the cloud, and the tension of its electricity. The hole forced by lightning in its passage through solid bodies varies in size from that formed by a small rifle ball to one foot or more in diameter. The following description of the recent effects of lightning on a dwelling-house, upon the island of Great Chebeaque, Maine, was furnished the Portland *Advertiser*, by an eye witness, and serves to show the prodigious quantity of electricity which occasionally passes from a highly charged cloud.

"The lightning appeared as a ball of fire, apparently a foot in diameter, with a trail some thirty yards in length. This passed down the chimney, shatter-

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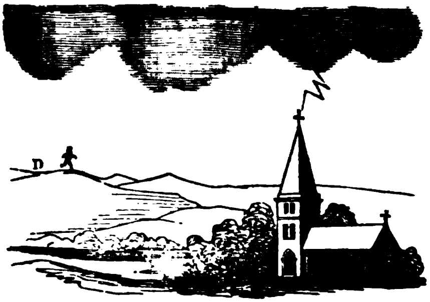
What kind of clouds generate electricity most rapidly? Give the appearance and phenomena exhibited by such clouds. Correspondence between a thunder-cloud and a Leyden battery? Course of the electric fluid between two clouds, in different states, but separated by a wide interval?

then from this to the negative cloud; the instantaneous passage of the fluid causes the lightning, in this case, to appear to descend to the earth from both clouds at the same instant. Oftentimes thunder-clouds, highly electrified, are seen to break upon the sides of mountains, or the surface of the ocean, when the discharges of lightning are directed wholly to the earth, and become frequent and violent in the extreme.

180. We have already shown the tendency of electricity to repel its like, and attract its opposite kind. Thus, when a cloud, A B, Fig. 178, highly charged, say with positive electricity, is suspended over and near the earth, it acts by induction, through the dielectric air, to repel the same electricity from that portion of the earth directly beneath, and attract its opposite. When such a cloud discharges, the return of the repelled fluid to the surface again sometimes produces a shock sufficient to destroy life. This is known as the *return stroke*, and by it

Fig. 178.



ing the house in a fearful manner, but not firing it. Nearly every article of crockery was broken in pieces; and two clocks, three looking-glasses, and two heavy oak tables were destroyed. Every chair in the kitchen was broken, and every partition removed from its proper position, and more or less shattered. The chair upon which the lady of the house was sitting was broken in twenty-eight pieces. The hole formed by the passage of the lightning through the floor into the cellar was sufficiently large for the passage of a man. A stone arch in the cellar, two feet thick, was rent asunder, in four

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Results when thunder-clouds sometimes break upon mountains, or the surface of the ocean? Explain, from the figure, how a person may be killed by a discharge from a cloud when several miles distant from the lightning. What is this form of stroke called?

a person on an elevation, at D, say, may be killed, although ten or twenty miles distant from the lightning of the cloud.

181. *Lightning-rods* are a comparatively recent invention, being one of the results of the practical investigations of Dr. Franklin. We have before shown the power of metallic points in attracting the electric fluid, and withdrawing it from electrified bodies. The phenomena of these suggested to the mind of that acute philosopher the idea of pointed metallic rods raised upon buildings, for protecting these against the dangers of lightning. These may be made from three-quarter inch nail-rod (although copper is preferable as a conductor), extending up from the chimney, and from the ends and corners of the roof, from three to six feet, and terminating in points;* the whole being connected with one or two main rods, conducting to the earth. These should enter the ground sufficiently deep to be always in contact with a moist earth; and may terminate in some powdered charcoal, or a spring of water. The space which a point will protect is much less than is often supposed; this being a sphere whose radius is twice the height of the point above the building. Thus, a point rising five feet above the roof will protect a spherical space of twenty feet in diameter; hence, the necessity of several of these upon a large building. The rods should be as entire as possible, and the stays used in holding them, if of metal, should not terminate in points near other metals within the frame of the building;

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places, and the cellar-wall twice severed from top to bottom, and the stones blackened as if by powder. Every window-sash in the house, with one exception, was demolished; five doors were shivered to splinters. A large trunk, filled with clothing, was subsequently opened, and its contents found to be covered with soot to the depth of half an inch. Several trees, at a distance of six rods from the house, were shattered in pieces; but, remarkable to say, amidst this general wreck, the inmates of the building escaped with life."

* Silver points are preferable.

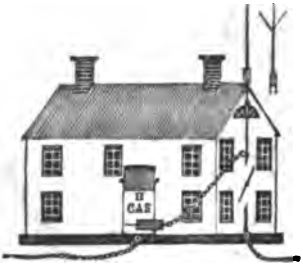
What is said in regard to the discovery of lightning-rods? How may they be made? How should they be placed upon a building? What space around will a pointed conductor commonly protect?

as, in case of an excess of lightning passing down the rod, a portion may pass along the stay into the building.

Some amusing experiments, illustrative of the uses and defects of lightning-rods, may be shown, as follows:

Experiment. — Place upon the Thunder-House, Fig. 179, either form of points. Without the metallic chain leading within, as shown in the cut, join the parts of the rod so as to make it entire, and connect the bottom, by a chain, with the outside of a charged jar; bring this jar near the point, when it will be *silently*, yet rapidly, discharged. Place a ball on the point, and the jar *will* now discharge with a flash, yet without harm to the building.

Fig. 179.



Experiment a. — Place, now, within the same, a small canister of explosive gas, as described in Experiment §166; connect this with the rod upon the inside, as shown in the cut, and bring the chain, connected with the metallic surface on which the canister rests, to the outside of a charged jar; break the connection of the rod a trifle, and bring the knob of the jar near the ball or point. The fluid, instead of passing as before, will be diverted into the building, exploding the gas, and scattering the parts of the house in every direction; thus, strikingly illustrating the disastrous effects which frequently proceed from *a defective lightning-rod.**

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* The parts of this miniature house are held together by magnets. One side of the roof may be removed for arranging the apparatus within. The canister, if tight, may be filled and adjusted before the lecture; in such case, the order of these experiments must be reversed. Powder may be substituted, by connecting with the rod by a wet string.

State the experiment with the thunder-house? Give Experiment *a*, illustrating a defective lightning-rod?

182. *Thunder* is caused by a sudden concussion of the air, which has been forced aside by the electric fluid in its passage through this; the *rolling sound* is produced by the reverberation among the clouds, and the return of the report from the varying distances along the electric line. The *zig-zag* course of lightning is, probably, caused by the condensation of the air before the fluid, which turns it aside from a direct line. Vapors, however, and different conducting media, may sometimes determine its course from a straight line.

183. *Places of Safety.* — The sudden and terrific effects of lightning render it a cause of universal dread, which naturally leads to an inquiry in regard to the proper precautions against its dangers. The directions are few and simple. Lightning-rods, properly constructed, are, undoubtedly, important safeguards against its effects in dwellings, and on board of vessels. As chimneys, charged with soot and smoke, are excellent conductors of the fluid, and very liable to attract it, a seat near a stove or fire-place, during a thunder-storm, should be avoided; also, against bell-wires, gilt mouldings, or by an open window, as the electricity is most certain to take these in its course through a building. The cellar, also, is an unsafe place of resort; the fluid often passing from the earth to the cloud, when the most disastrous results may be effected in the basement.

Reclining upon a feather-bed, sitting in the centre of a carpeted room, or standing upon a thick rug, are tolerably safe positions.

If out of doors, trees, especially those standing near bodies of water, should not be sought for shelter; but rather cliffs of rocks, low sheds, caves, etc. The chances, however, of death from lightning are exceedingly few, less even than from the fall of chimneys, the upsetting of carriages, or a thousand similar liabilities, which seldom occasion the least solicitude.

How is thunder caused? Cause of the zig-zag course of lightning? What are some of the dangerous positions during a thunder-storm? Some of the more safe positions?

184. *Heat-Lightning* is probably a reflection of the flashes of lightning produced by storms actually below the horizon.

185. The *Aurora Borealis* is undoubtedly the result of an electric agency. Various theories have been entertained in regard to the probable cause of this singular phenomenon; but nearly all unite in ascribing this in some way to the electric fluid. De La Rive, a philosopher, whose opinion on such subjects is entitled to much regard, explains the cause of the Aurora as follows:

The constant escape of positive electricity from the earth, by evaporation, renders the upper atmosphere highly positive, and there is consequently a continual tendency to restore the equilibrium between this and the earth. Although, by electrical discharges from clouds, and by the fall of rain and snow, this is partially effected, yet the main channel, through which the fluid passes to the earth, is found to be at the magnetic poles. Thus, the quantities of electricity which pass into the atmosphere, about the equatorial regions, flow towards the poles, and are discharged into the earth at the extremities of the magnetic axes, and from thence flow again to the equator, thus forming a constant and continuous electric circuit through the upper atmosphere toward the poles, and through the earth toward the equator.

The streamers of auroral light are caused by the passage of electricity in a circle, from the regions above the magnetic pole toward this pole. In demonstration of this theory, De La Rive caused one of the poles of a straight magnet in connection with the earth to enter a glass globe. Around and above the end of this magnet was fixed a metallic circle, in communication with an electric machine. Upon removing the air from the glass globe by means of the air-pump, and charging the metallic circle from the electric machine, the fluid was found to

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How is heat-lightening probably caused? By what agency is the Aurora Borealis probably produced? Give the experiment of De La Rive, for illustrating the cause of the Aurora. What evidence have we that the Aurora is connected with the magnetism of the earth?

pass from all parts of the ring towards the pole of the magnet, forming streams of dim light, and a halo resembling with much precision the phenomenon of the Aurora.

That this is connected in some way with the magnetism of the earth is evident from the fact that the magnetic needle is found to be more or less affected by north and south currents during auroral exhibitions.

The Aurora often affects most sensibly the operation of the Electro-Magnetic Telegraph, causing the register of this to operate as if connected with a powerful battery. The irregular action of the telegraph during the day sometimes gives the signal of an Aurora, which is verified by its appearance at evening.

The affection by the Aurora is most sensible in Bain's Chemical Telegraph. Thus, by its effects upon the telegraph, this illumination is shown to be connected in some way with the electric agent.

What is said of the Aurora in reference to the Electro-Magnetic Telegraph ?

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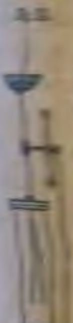

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GALVANIC ELECTRICITY.

186. Occurrences, the most trivial in themselves considered, are often suggestive of principles the widest and most important in their application. In about the year 1789, Galvini, a professor of Anatomy, at Bologna, had his attention one day arrested by the following singular phenomenon. Some frogs' legs, prepared for a soup for his wife, who was an invalid, were suspended by copper hooks connected with an iron railing. As these were moved by the wind or other cause so as to touch the iron, they were noticed at the same instant to become convulsed, and exhibit a peculiar twitching movement, as if possessed of vitality. Galvini at once commenced a series of experiments, and produced the same phenomenon, in a more marked degree, by the application of various metals to the nerves and muscles of the legs of frogs freshly prepared; and hence, from so slight a circumstance, was laid the foundation of that branch of physics, named from its discoverer *Galvanism;* a science, which has of late contributed in such a wonderful degree to the progress of art, and to enhance the physical and social well-being of community.

Galvini attributed these movements of the muscular system to a nervous fluid, which passed from the nerves to the muscles, to restore an equilibrium whenever the metals connecting with these were touched together, producing at the same time a convulsive shock, similar to the attempt to restore the disturbed equilibrium of a charged Leyden Jar.

187. Volta, a distinguished electrician, soon after instituted a series of experiments, to refute the theory of Galvini, and showed that no electrical or nervous excitement took place, un-

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State the circumstances connected with the discovery of Galvanism. What is said of the importance of this branch of science? To what did Galvini attribute these singular movements of the frogs' legs? What did the experiments of Volta show?

less the metals connecting the parts of the animal were of different kinds, as iron and copper, or copper and zinc; he was hence led to refer these singular results to the development of free electricity by a *contact of the metals.* Thus, in the case of zinc and copper, when in simple contact, free positive electricity was found to be evolved from the former, and free negative electricity from the latter. These Volta attributed to a peculiar electro motive force, under which metals by simple contact tend to assume different electrical states.

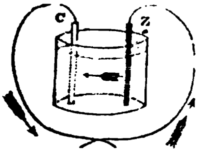
The late experiments of De La Rive, Faraday, and other distinguished philosophers, have overthrown the theory of Volta also, and proved this form of electricity to be in every instance the result of chemical action.

The discovery of the Voltaic Pile by Volta, in about the year 1800, served to establish, beyond a doubt, the identity of electricity and galvanism, and gave a new phase to this wonderful branch of science.

188. *When two metals, differing in their susceptibility of oxidation, are connected and placed in some liquid capable of acting more powerfully on one than on the other, that form of electricity known as galvanism or electricity in motion is produced.*

Experiment. — Pour into the glass vessel, Fig. 180, some dilute sulphuric acid, and in this place two metallic plates, one of zinc and the other of copper, with wires attached as in the cut. If, now, the wires be joined, a *galvanic circle* will be formed; the water of the liquid becoming decomposed,* its oxygen will unite with the zinc (the more oxida-

Fig. 180.



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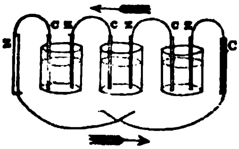
* Water is a compound, formed by the union of the two simple gases oxy-

To what was he led to refer these results? What is said of the late experiments of De La Rive, Faraday, and others? What did the discovery of the Voltaic Pile serve to establish? State the proposition section 188. State the experiment illustrating this.

ble metal), and at the same time a current of electricity will be transmitted through the liquid to the copper, on the surface of which hydrogen, the other element of water, will appear in the form of minute bubbles of gas; this current of electricity passes around through the wires in the direction indicated by the arrows, and returns again to the zinc where it originated; and thus a constant electric current is maintained, so long as the wires are made to touch; but separate these, and the flow instantly ceases, and so continues until contact is again made. Such an arrangement constitutes a *Simple* Galvanic Battery. If a series of these metallic plates be made to alternate, each copper being joined to its corresponding zinc, as shown in Fig. 181, it forms the Voltaic Pile or *Compound Battery*.

Fig. 181.



189. The copper plate, or extremity at which the electricity passes *from* the liquid, is termed the *positive pole*, while the zinc plate, or extremity where it *enters* it again, is called the *negative pole*. These poles have also been styled, by Dr. Faraday, *electrodes*,* or ways for the electricity; the positive pole being called by him the *anode*,† or ascending way, and the negative pole the *cathode*,‡ or descending way, or path for the electric fluid; these terms expressing more clearly the direction of this in its flow through the parts of the battery.

190. It is not necessary, in order to form a galvanic circuit,

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gen and hydrogen. These are in different electrical states, one positive, and the other negative. The poles of the Galvanic Battery having a stronger attraction for these than they have for each other, they separate and go to their respective poles. The same is true of other compounds besides water.

* From the Greek, ἤλεκτρον, electricity, and ὁδός, way.

† ἄνα, ascending, οδος, way. ‡ κάτα, descending, οδος, way.

What does such an arrangement constitute? What constitutes a Compound Galvanic Battery? What is the positive pole? What is the negative? What were these poles styled by Faraday?

that there be two different metals, or two kinds of liquids, provided certain other conditions be attended to. Thus, if a single plate of zinc be so fitted into a wooden trough as to form of it two separate cells, and into one of these, upon one side of the metal, there be poured some dilute acid, and into the other, upon the opposite side, a solution of common salt, a current of electricity will at once commence to flow through wires connecting the two sides of the plate; or if the same liquid be used in both cells, and one side of the zinc plate be rough and the other smooth, a like action will result. Thus, in order to excite galvanic action, it is only necessary to produce different degrees of chemical action on different plates of metal, or on opposite sides of the same plate.

191. *Galvanic electricity is characterized by its immense quantity and continuous flow, but feeble tension; frictional or machine electricity, by its limited quantity and irregular discharge, but high tension, and the great energy of its mechanical action.* — The machine electricity, employed in the experiments of the previous sections we have shown to be possessed of a remarkable degree of tension, which required the most perfect insulation, in order to prevent its escape from the surface of the bodies upon which it was desired to retain it; and its quantity, although small, was characterized by a spasmodic, yet wonderful energy of action. Galvanic electricity, on the other hand, is evolved in prodigious quantities, yet with a steady and continuous flow, and may pass through conductors, but slightly separated from other conducting media; thus, the wires which conduct away the electricity produced from a powerful battery require only the insulation afforded by a coat of varnish or cotton thread, while, in the case of electricity produced by mechanical means, these conductors require a separation of a considerable distance.

How may a galvanic current be produced by a single metal or a single liquid Distinction between galvanic and frictional electricities?

The following illustration may, perhaps, best serve to convey an idea of the nature and effects of these two forms of electricity. Suppose a reservoir for water to be situated upon an eminence, and supplied by a constant flow from an adjoining spring, and from this reservoir a pipe conduct to the region below. If this pipe be left open, so that the water may have a free and continuous passage from the reservoir, the quantity passing in a given time, although great, will not be suffered to accumulate, so that its force will be comparatively feeble and unobserved; but if, now, this pipe be provided with a valve at its lower extremity, which shall remain closed, and open only as the reservoir becomes filled, and the intensity of the pressure from the accumulated water too great to be longer withstood, a violent bursting forth of the fluid will occur at stated intervals, accompanied by effects the most forcible and energetic. Thus, with a comparatively small quantity of liquid under a high pressure, more striking effects may be produced than with a very much larger amount unrestrained. So of the results of the electricities excited by frictional and galvanic action, while the former produces its effects through an *accumulated* and *intensified* action, the latter, flowing forth in a mighty yet continuous stream, works its changes through its *quantity*, rather than by any concentrated power.

192. *The tension of galvanic electricity may be increased, and made to approximate to that produced by the electric machine.*— This may be effected by increasing the number of the pairs of metals employed in exciting the galvanic current. The *quantity* of electricity set in motion by a *single* pair of metallic plates is the same as that from a long series of the same, while the *intensity* of this varies with the *number* of the plates forming the galvanic circuit. Thus, a single pair

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Illustrate the natures of the two electricities by the flow of water. State the proposition section 192. How may the tension of galvanic electricity be increased, and made to approximate in its effects to machine electricity? What is said of the quantity of electricity set in motion by a single pair of plates of plates, however large, can never produce electricity of sufficient intensity to decompose water, or give the slightest shock to the animal system; while, if the same be divided so as to form a number of small plates with an equal surface, and these be arranged as in Fig. 181, electricity may be excited of sufficient intensity to produce sparks, and give vigorous shocks, similar to those received from the Leyden Jar; indeed, a galvanic battery, composed of a sufficiently extended series, may be made to produce nearly the same results as the common electric machine, giving violent shocks, emitting sparks, charging jars, etc.

The increase of the intensity of the electric fluid with the increase of the galvanic series is due to the resistance which it meets in its passage from one series of metals to another through the liquid, each series imparting to it an additional momentum or intensity, which becomes greater in proportion to the number of the pairs of metals by which it is urged forward.

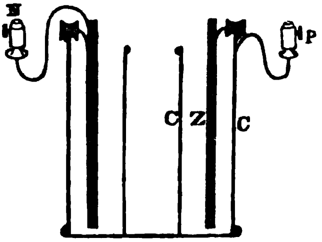
193. *The heating and magnetic effects of galvanic electricity depend on its quantity rather than its intensity; and this varies with the amount of chemical action or the extent of the metallic surface on which this action is exerted.* — Thus, for extensive heating and deflagration, or for powerful magnetic results, the *size* of the plates should be regarded. Batteries constructed with reference to this, are termed *deflagrators*, from the energy with which metals and other combustible bodies deflagrate or burn, when made to form a portion of the galvanic circuit. For heating, and magnetic effects alone, a single pair of metallic plates only is required; but certain experiments, as we shall have occasion to show, depending for their success on *both* quantity and intensity, require that both the *size* and *number* of the plates forming the series be regarded.

What is said of the results from dividing such a pair of plates, so as to form from them a series of smaller plates? To what is the increase of the intensity of the electric fluid in such case due?

194. *Galvanic Batteries.*— These are constructed of various forms and sizes, according to the purposes for which they are intended. The general theory of their operation has been already given (§ 188); it only remains to describe a few of the more common forms, and give some general directions in regard to the manner of their use.

The simplest form of battery now employed, is that devised by Mr. Smee. This is shown in Fig. 189, where a plate of platinum or copper, C, forms the electro-negative metal, and plates of amalgamated zinc, Z Z, the electro-positive metal. This plantinum is usually suspended between two plates of amalgamated zinc,* from a wooden frame resting on the top of the glass receiver. The wires or poles for directing the current of electricity, in this, as in the subsequent forms of the battery, are connected with the zinc and copper or platinum plates, by means of small screw-cups, so as to be easily removed when desired.

Fig. 182.



Sulphuric acid, diluted with ten or twelve parts of water, is the liquid employed for exciting galvanic action. This form of battery is extensively used where uniform and long continued action is required, as in processes of electrotyping yet to be described.

195. The *Sulphate of Copper Battery*, of which Fig. 182 presents a sectional view, consists of two cylinders of copper, C C, tightly soldered to a copper bottom. Midway between these,

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* The zinc plates, employed in all batteries where dilute acid is used, should be amalgamated with mercury. These amalgamated plates may be prepared by pouring upon mercury, in a saucer, some dilute sulphuric acid, and then brushing the liquid and mercury over the surface of the zinc, until the whole is covered with a bright coat of mercury.

On what do the heating and magnetic effects of the Galvanic Battery depend, and how do these vary? Describe the Sulphate of Copper Battery.

by means of three wood or ivory supports resting on the outer cylinder, is suspended a thick cylinder of zinc, Z, so as to remain insulated from the copper surfaces. Two screw-cups, P and N, for holding the connecting wires, are attached, one to the outer copper, and the other to the zinc. The liquid used is a solution of sulphate of copper (blue vitriol) in water.* This is poured into the space between the copper cylinders, and acts on both surfaces of the zinc,† evolving a current of electricity, which passes through the liquid to the copper, and so out through the positive wire, as already explained. This battery may be advantageously employed for propelling the various forms of electro-magnetic engines, described in the following sections.

Fig. 183.

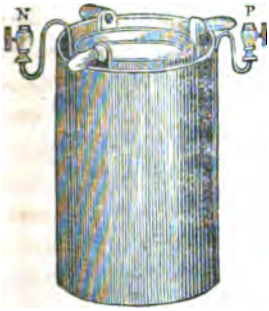

Fig. 183 presents a perspective view of the Sulphate of Copper Battery.

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* About two ounces of this salt to the pint is a convenient proportion; as cold water dissolves this slowly, the process may be hastened, when necessary, by warming the liquid. Sulphate of copper is composed of sulphuric acid combined with oxide of copper.

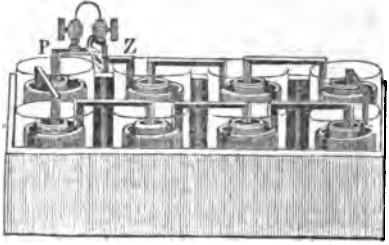
† The action of this battery is as follows: The oxygen of the water forms with the zinc an oxide of that metal. With this the sulphuric acid of the salt combines to form a sulphate of zinc, leaving the oxide of copper, which is deposited on the surface of the zinc, or falls to the bottom of the liquid, as a fine black powder. The hydrogen, the liberated element of the water, instead of escaping into the air, unites for the most part with the oxygen of the deposited oxide of copper, and again forms water, while the pure metal adheres to the surface of the copper cylinders as a light red powder.

The zinc cylinder should be removed from the solution, and suffered to air, as often as once in fifteen or twenty minutes. When the zinc surface has become too much coated with the copper oxide, it greatly enfeebles the action of the battery, and should be cleaned with a wet sponge, or fine wire card prepared for the purpose. When the solution has become too much saturated with the sulphate of zinc, it should be thrown away, and a fresh supply of liquid, prepared as above, should be introduced.

196. The *Self-Protecting Sulphate of Copper Battery* is a form of battery, devised by Professor Daniell, for obviating the objections to the use of that last described. A cylinder of zinc is inclosed in an ox-gullet, or, which is better, a porous earthenware cup, which separates it from the outer or copper surface of a copper receiver. The space within the cup around the zinc cylinder is filled with a solution of sulphate of soda (Glauber's salts); while that without and next the copper is occupied by a solution of sulphate of copper (blue vitriol), as in the previous section. By this arrangement, whereby two different exciting liquids are employed, such an interchange of elements takes place through the interposing earthen, as leaves the surfaces of the two metals comparatively *clean and free* from an oxide deposit, and thus renders the action much longer and more uniform.

197. A cheap, simple, yet efficient form of *Compound Battery* may be made, by placing plates of zinc and copper in a series of glass vessels, and then connecting each set, as shown in Fig. 181. The exciting liquid for filling the glasses may be sulphuric acid diluted with from ten to fifteen parts of water. This series may be extended to any number, forming a battery of proportionate intensity and power.

Fig. 184.



198. *Grove's Battery.* — This is an exceedingly efficient form of the Galvanic Battery, and is now quite extensively employed for telegraphing and other purposes requiring quantity as well as intensity of galvanic action. The construction and arrangement of the various parts may be learned from Fig. 184. Into a plain glass tumbler of about one pint capacity,

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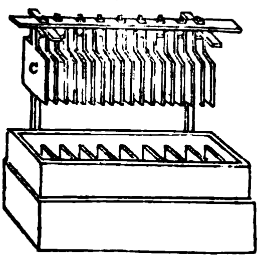
How may a cheap yet efficient form of Compound Battery be made? What is said of Grove's Battery? How constructed? Describe the manner of using is placed a thick cylinder of amalgamated zinc, standing on short legs, and divided by a longitudinal opening on one side, to allow a free circulation of the liquid. Within this cylinder is an unglazed porcelain cell, in which is suspended a strip of platinum soldered to the end of a zinc arm projecting from the adjoining zinc cylinder. When a series of these are arranged, as in the cut, to form a compound battery, the terminal strip, P, with its screw-cup, is supported by the first zinc cylinder, Z, but is insulated from it by a piece of ivory. Strong nitric acid is used in the porcelain cell in contact with the platinum, and sulphuric acid, diluted with ten or twelve parts of water, in the outer vessel containing the zinc.*

199. *The Trough Battery.*—This battery, Fig. 185, as originally constructed by Mr. Cruikshank, consisted of plates of copper and zinc united together in pairs by soldering at one point only, so as to be lowered into the separate cells of a wood trough; these plates were attached to a strip of wood, and so arranged that when lowered into the cells of the trough beneath containing the exciting liquid, each pair should enclose a partition between them. The principle of this arrangement and action is the same as shown by Fig. 181; it possesses,

Fig. 185.



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* Owing to the strength of the acids used, and the widely different oxidizable qualities of the two metals employed, the chemical action of this battery is great; and the quantity and intensity of the electricity evolved from a given surface exceeds that from any other form of battery now used.

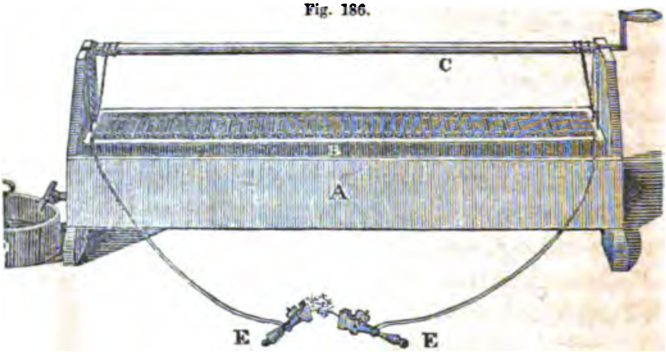
This form of battery is, however, objectionable for common purposes, owing to the risk attending the use of such strong acids by inexperienced manipulators, and the corrosive nature of the nitrous acid fumes given off during its action; these being not only injurious to health, but acting readily on the polished metals of a close room.

How are the plates of the Trough Battery arranged?

however, a decided advantage over that, in the fact that the whole series may be lifted at once from the cells, when desired, and further action thus checked.

Fig. 186 shows a modern and far superior arrangement of the Trough Battery. In this form the zinc plates are inclosed in copper cases, open at the top and bottom, thus doubling the surface as compared with the last.*

Fig. 186.



The whole series is also confined in a wood case, B, which may be raised or lowered into the trough, A, containing the acid, by means of the windlass, C. E E are small hand-vices connected with the poles for holding wires, bits of charcoal, etc., for deflagration. The exciting liquid is sulphuric acid diluted with about thirty or forty parts of water; where extraordinary action is required the proportion of this acid may be increased.

The greatest power of this battery is attained soon after the

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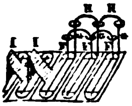
* The arrangement of these plates is shown in cut at the left. Each plate is held firm in its copper by bits of grooved wood arched to fit the copper case and placed at its top and bottom. Between the copper cases are fixed thin strips of veneer. These, with the bits of wood just referred to, are boiled in a mixture of oil and resin, to render them impervious to water, and thus improve their insulation. The connection between the series is formed as shown at I I, a strip of copper leading from the copper case being soldered to a projection on the zinc of the next set. The arrangement, H H, etc., is designed to show the manner of converting this battery into a calorimeter, by connecting all the copper and zinc plates so as to form one continued surface.



immersion of the plates;* advantage should be taken of this fact, and these not suffered to remain too long in the acid, but often raised and allowed to air.

For purposes of decomposition and deflagration, the Trough Battery possesses superior advantages, combining both convenience and efficiency. The expense and skill requisite in their construction have caused a quite general substitution of Grove's Battery. Fig. 186 shows a battery of fifty pairs, which, for the actual space occupied, exceeds in power all other forms.

200. The important relations of the galvanic battery to researches in this department of electricity, have led us to enter thus at length into a description of the principal forms; we now pass to consider further some of the principles which it unfolds.

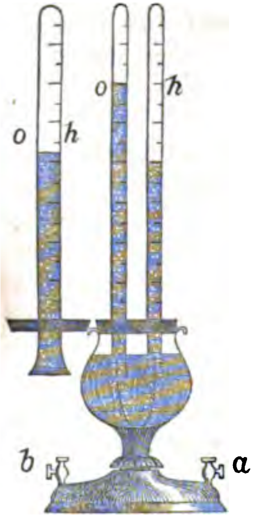
201. *In every chemical combination the force by which the elements are held together is regarded as an electrical force.*—We have already shown, § 151, that bodies in opposite electrical states, are attracted to each other. Thus, if two elements of a chemical compound, charged with opposite electricities, are brought sufficiently near, these will be attracted and held together by a force proportioned to the difference of their electrical states. Thus, the difference in the electrical states of oxygen and hydrogen (the elements of water) is comparatively slight; hence the feeble affinity existing between these, and the ease with which they are separated when united to form water. Oxygen and potassium (the elements of potash), on the other hand, differ widely in these respects; the former being at the extreme of the electro-negative, and the latter at the extreme

* This battery should be wet up with an extremely weak solution some time previous to use, and additional strength given to this when wanted for action. All contact of the plates, or communication between these, by means of straws, etc., should be carefully avoided, as by such neglect the power of the battery is oftentimes wholly defeated.

In case of decomposition or deflagration, what is said of the Trough Battery? By what force is it supposed that the elements of a chemical compound are held together? With what proportional force are the elements of such united? Illustrate this in the case of oxygen gas and potassium.

of the electro-positive elements. As a consequence, these are drawn together, and united by a force superior to that of any of the binary oxides, and require for their separation agencies of the most intense decomposing energy. Thus, all chemical affinity has been regarded by Faraday and other distinguished electricians as simply a modification of electric attraction.

Fig. 187.



202. *Experiment.* — Let two glass tubes be filled with water, rendered slightly salt or acid,* and inverted in a cell of the same liquid, over two wires, terminated by small strips of platinum, as shown by Fig. 187. If, now, these wires be connected with the poles of the batteries, Fig. 184 or 186,† small bubbles will be seen to escape rapidly from the platinum strips, rising and displacing the water of the tubes; the tube *h* connected with the *negative* pole of the battery, containing at any time about *twice* the volume of gas found in the tube, *o*, connected with the *positive* pole of the same. Place corks in these, and invert. If a lighted taper be now applied to the mouth of the tube, *h*, the gas will burn with a dull flame, showing it to be *hydrogen ;* if the same taper be extinguished,

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* These increase the power of the liquid to conduct electricity, and thereby facilitate its decomposition.

† A large-sized Sulphate of Copper Battery, Fig. 183, may be advantageously employed, by interposing the Vibrating Shocker, Fig. 226, between it and the Decomposing Cell.

How may the elements of which water is composed be separated?

except a lingering spark, and placed in the tube, *o*, it will be instantly relighted, proving the presence of *oxygen.*

The theory of this decomposition is as follows: By means of galvanic action the electrical affinity of the two elements for each other is overcome; the hydrogen, the positive element of water, being drawn to the negative pole of the battery, while the oxygen, the negative element, passes to the positive pole. By this means, moreover, the relative *proportions* of the elements in water and all other chemical compounds are determined, and found to be definite and unvarying. Thus, in the case of water, as just shown, the proportions are *two* parts by *volume* of hydrogen, combined with *one* part of oxygen.*

Experiment a. — In place of the double tubes, as in the last experiment, fill, and insert the single tube, *h o*, causing *both* points to enter its mouth. Connect with the battery; the tube will soon be filled with a highly explosive mixture of oxygen and hydrogen gases, as may be shown by inverting and applying a lighted taper. By such an explosion the gases will unite, and again form water.

In these experiments the volume of gas liberated is in exact proportion to the quantity of electricity passing through the liquid. This decomposing cell is hence termed a *Volta-scope*, or measure of electricity.†

203. In this decomposition of water by galvanic action, as in that of other chemical compounds, the process by which the elements are simultaneously evolved at the poles of the battery is supposed to be briefly as follows:

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* The simple or elementary substances, of which matter in its almost infinite variety of forms is composed, are supposed to be only about sixty; forty-eight of these are metallic and twelve non-metallic substances.

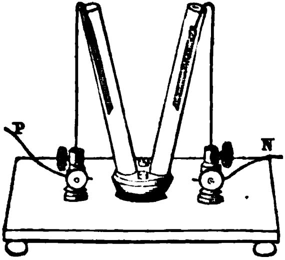
† In the decomposition of liquids, regard must be paid to the *quantity* of these. A small battery will act only on a proportionably small amount of liquid. Ignorance of this fact often occasions failures in the use of the Decomposing Cell, Fig. 187.

What proportions do oxygen and hydrogen unite to form water? Theory of the decomposition of water by the galvanic current?

Each atom of water, for instance, is composed of two elements, oxygen and hydrogen. Now, suppose a series of these atoms to lie between the battery poles; that atom at the extremity of the series next the *positive* pole, for instance, will be decomposed, its *oxygen* being drawn to, and evolved at, this pole, while its ***hydrogen***, being repelled from this, and attracted toward the opposite *negative* pole, will force along the hydrogen of the *next* adjoining atom, and unite with its oxygen, while the hydrogen of the next atom in the series will, in *its* turn, be displaced; and so a series of decompositions and recompositions will take place through the whole line, until coming to the last, next the negative pole; the hydrogen driven off from this, having no element with which to combine, is evolved in the form of a minute bubble of gas, as shown by Experiment § 202. Thus, no actual *transfer*, but simply an *interchange* of the elements of the compound, is effected, whereby those at the extremities of the series next the galvanic poles are liberated and appear. By a similar process of interchange the decomposition of the more complex alkaline compounds is produced.

204. *Experiment.*—Let the poles of the battery be terminated by small strips of platinum, placed in a bent tube fixed in a stand, as shown by Fig. 188. Pour into this tube a solution of sulphate of soda, to which has been added a sufficient infusion of red cabbage to give to it a blue color. Upon the passage of a current of electricity, the *blue* color will soon be changed to *red* in the arm containing the positive pole, and to *green* in the one containing the negative pole; showing in the former the presence

Fig. 188.



State the supposed process of interchange of elements in the decomposition of each atom of water. What change will be effected in an infusion of red cabbage, through which a galvanic current is made to flow as shown in Fig. 188?

of sulphuric acid — one of the compound elements of the salt — and, in the latter, that of soda, its other compound element. Now, reverse the current, and the original color will first be restored in each arm of the tube, and then the opposite change will occur.

Experiment a. — Fill the tube, Fig. 188, with a solution of iodide of potassium, to which has been added a little starch, and send through a galvanic current. The iodine will be freed from its combination, and appear at the positive pole, giving with the starch an intensely blue color to the liquid in the cell containing that pole.

205. *Electro-Metallurgy.* — When metallic salts, as sulphate of copper, are dissolved in water, and a current of electricity from a galvanic battery passed through the solution, such salts are decomposed (see § 195, note); the oxygen or electro-negative element of the base * going to the positive pole, while the metal is deposited on the wire, or other metallic surface at the negative pole. If, in this case, proper skill be exercised in regulating the electric current, and the consistency of the saline solution, the deposit will take place with remarkable evenness and regularity, forming what is termed the *reguline* deposit.

Experiment. — Connect by soldering, or otherwise, to the negative wire (that leading from the zinc plates), of a Smees Battery, a medal, coin, or other metallic object. Smear the

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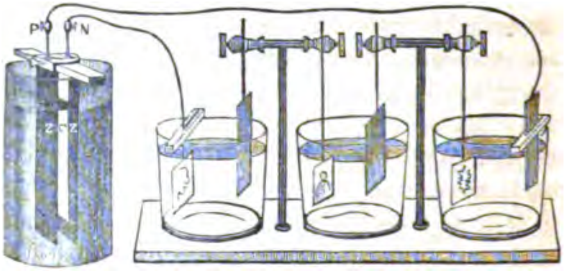
* The *base* is the principal ingredient in a chemical compound, or that with which acids, etc., combine. In this case, oxide of copper (copper rust) forms the base, with which sulphuric acid combines to form the salt, sulphate of copper.

What change will be effected in a solution of iodide of potassium? What is the effect of passing a galvanic current through water in which is dissolved a metallic salt, as sulphate of copper? In this case, what is said of the deposit of the metal? If proper skill be exercised in regulating the electric current and consistency of the solution, how will the metal be deposited on a metallic surface? State the manner of preparing and arranging the objects on which a metallic deposit is to be formed.

back and edges with a coating of wax or varnish, to protect these parts against the effects of galvanic action. Attach to the end of the other positive wire a small piece of sheet-copper, and then immerse this with the medals, etc., in a solution of sulphate of copper, in a glass tumbler, with the unprotected surface next to and near the copper. Fig. 189 shows a convenient arrangement, where three separate medals are being copied by the action of the same galvanic current. A bright film of pure copper will soon form on the coin or medal; and, if the action be continued for a day or more, the metal will acquire considerable thickness, and may be removed, when it will be found to present a smooth and perfect transcript of that portion of the surface on which it has been deposited.

Fig. 189.



Experiment a. — Form a smooth and perfect mould by impressing on wax, stearine, or fusible metal when in a plastic state, a medal, wood-engraving, or other object. When hard, cover this mould with a smooth and delicate coating of plumbago;* connect this with the negative wire of the battery, and immerse in a solution of sulphate of copper,† as in the previous experiment. A smooth and firm deposit of copper will, in the course of a day or two, be made on the portion covered with the plumbago, and, when removed, will be found to contain all the nice irregularities of the original. In this manner duplicates of wood-cuts, type, etc., may be obtained, from which impressions can be taken fully equal to those of the originals.

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* The copper wire should be placed carefully *around* the edge of the mould, so that the deposit, which begins at the wire, may be on all sides alike. The plumbago may be put on with a camel's-hair brush. This serves as a conducting surface.

† Pieces of the sulphate of copper should be from time to time placed in the tumbler, as the solution becomes weak and pale.

206. By a somewhat similar process, gilding with the precious metals is effected; these being deposited from their solutions on metallic surfaces by the same galvanic action.*

Since its discovery by Professor Jacobi, in 1837, Electro-Metallurgy has been carried to a wonderful degree of perfection, and now holds an important rank among the useful arts. For further information upon this interesting subject the reader is referred to works especially devoted to this art.†

207. *The heat evolved by an electric current is in proportion to the resistance offered to its passage through a body.* — In respect to their powers of conduction, metals differ widely; thus, while a silver or copper wire will transmit the electric current from a battery freely and without heat, a platinum or steel wire of equal size and length may afford so much resistance as to heat and melt or even ignite the wire.

Experiment. — Place between the poles of a Grove's or a Trough Battery, of medium size, one or two feet of number thirty steel wire. Upon the passage of the galvanic current, this

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* An improved manner of electro-gilding has been recently devised by a German, and adopted by a portion of the artists of this city. Instead of the battery heretofore employed, the electric current is produced by a magneto-electric machine or *dry* action. By this arrangement the deposit is formed with far greater rapidity than by that of the common battery.

† Davis' Manual of Magnetism and Walker's Electrotype Manipulations may be profitably consulted.

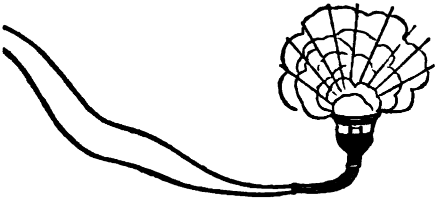
How may metallic copies of medals, wood-engravings, etc., be formed? What is said of the heat evolved by the passage of an electric current through a body? Do all metals conduct electricity alike? What illustration given of this? State the experiment for igniting steel wire.

will become intensely heated, and ignite with brilliant scintillations.* Platinum wire of a larger size may be burned in the same manner.

Experiment a.—Inclose in a small and thin glass tube, about one foot in length, a spiral of small steel or platinum wire, coiled as close as may be without a contact of the spirals. Let the ends project through corks, and connect with the poles of the battery, as in the last experiment. The electric current will soon heat the wire and tube, so that if the latter rest in a small quantity of water, this may be raised even to a boiling heat.

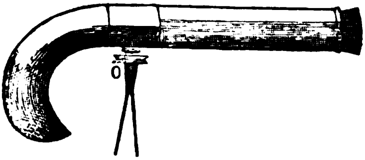
Experiment b.—Place in the *Powder-Cup*, Fig. 190, some fine powder, and connect its wires with the poles of a Sulphate of Copper Battery; the passage of even a feeble current across the fine *platinum* wire, which joins their ends within the cup, will so heat this wire as to explode the powder. †

Fig. 190.



The *Galvanic Pistol*, Fig. 191, is provided with an arrangement similar to that of the Powder-Cup in the previous experiment. Two insulated wires or poles pass through the screw-plug, *o*,

Fig. 191.



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* The Universal Discharger, Fig. 165, Mechanical Electricity, may be conveniently used for holding these wires.

† By means of a platina wire passing through the powder of the priming-hole, experiment § 166 may be performed by the Galvanic Battery instead of the Leyden Jar.

How is the powder ignited in the Powder-Cup? How may explosive gases be fired by the galvanic current?

upon the under side of the pistol, and are joined at their extremities by a platinum wire.

Experiment c. — Fill this pistol with an explosive mixture, as directed in § 143, and, with the cork tightly inserted, connect the wires with a Sulphate of Copper Battery, when the platinum wire will become of a glowing heat,* and explode the gases, forcing out the cork with a loud report.

Experiment d. — Hold in the vices or pincers attached to the poles of a Trough or Grove's Battery two small pointed cylinders of boxwood charcoal. With the battery at its highest point of action, bring these charcoal points together, when a spark will pass, and the points become ignited. These may now be separated to a greater or less distance, according to the power of the battery, and an arch of light of the most intense brilliancy will be formed between the points. The ignition of the charcoal in this experiment is independent of the aid from oxygen gas, as in ordinary combustion, since the same light may be produced equally well in a vacuum. The cause, however, appears to be due to the transfer of the particles of charcoal in a state of ignition from the positive to the negative pole. Both the quantity and intensity of the galvanic current are to be regarded in this experiment, and hence the larger the plates, and the more numerous the series, the greater will be the brilliancy of the result.

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* In all galvanic experiments, where the connections are in part of fine platinum or steel wire, regard should be had to the power of the battery, lest the quantity of the galvanic current be so great as to melt or ignite these wires. Such experiments are generally best performed by the Sulphate of Copper Battery.

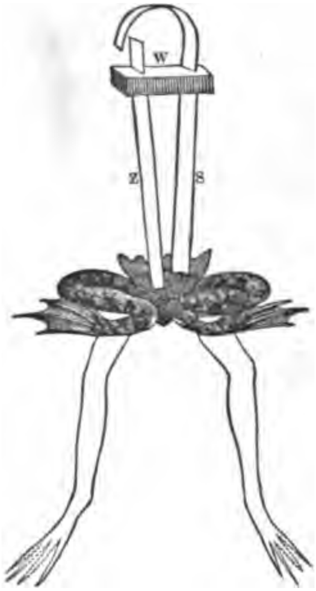
What is said of the light from charcoal points ignited by the Galvanic Battery? In the case of the intense ignition of these charcoal points by a current of galvanism, is the presence of atmospheric air or oxygen gas necessary.

PHYSIOLOGICAL EFFECTS OF GALVANISM.

208. *Whenever any portion of the body of an animal, living or recently killed, is made to form a part of the galvanic circuit, a violent contraction of the muscles of that portion takes place.*

The nerves of certain animals form one of the most delicate tests known of the passage of an electric current. As we have already remarked, §158, it was the twitching of the legs of frogs occasioned by the contact of two different metals, that first suggested to Galvini those experiments which led to the discovery of the wonderful science which bears his name. This singular phenomenon may be shown by the following

Fig. 192.



Experiment.—Let two pieces of metal, one of silver, S, and the other of zinc, Z, be fixed in a small block of dry wood, as seen in Fig. 192, and let the former be so curved as to touch the latter, upon a slight pressure of the finger, as shown by the figure. Remove the hind legs of a large frog, recently killed, from the body, so that they shall remain joined together, and place these between the metals so that one metal shall touch the large nerve proceeding from the legs, and then the other the muscle where the skin has been stripped off. Upon a contact of the metals above the block, a galvanic current will pass, and the legs

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State the effects of galvanism on the animal system. What is said in regard to the nerves of certain animals? How may the effects of galvanism upon the legs of a frog be shown?

which hang, as indicated by the dotted lines, will instantly undergo a wonderful contraction, and be drawn up as seen in the cut.*

Experiment a. — Place on a moistened plate of zinc a piece of silver or platinum, and on the latter put a leech or earth-worm. As often as the animal attempts to leave the silver, it will receive a violent shock, as will appear from its sudden withdrawal and return to this again.

Experiment b. — Place a piece of zinc above and one of silver below the tongue, when well moistened by saliva. Make a contact of these metals thus arranged, and a slight twinge, accompanied by a disagreeable metallic taste, will be the result. This is due to the oxidation of the zinc and the passage of a galvanic current.

209. By a powerful galvanic battery, convulsions, similar to those of the legs of the frog, may be produced on the bodies of larger animals and men, soon after death, such as to induce a belief that the animal has been restored to life, and is enduring the most cruel sufferings. Thus, if the two wires from the poles of a large battery be inserted in the ears of an ox or sheep, when the head has been removed from the body of the animal recently killed, the most surprising convulsions will result as often as the galvanic current is made to pass. The eyes will be made to open and shut, and roll in their sockets, as though again endued with vision; the nostrils will vibrate, as in the act of smelling, and the jaws imitate all the movements of mastication. The experiments of Dr. Ure, upon the body of a muscular, athletic man, who had been hung for murder, are truly wonderful. When the galvanic current from

* Davis' Manual.

In Experiment *a*, why does the leech or earth-worm draw back as it touches the zinc? What effects may be produced by the action of a powerful battery on the bodies of animals recently killed? Effects in traversing the head of an ox or sheep? Experiments of Dr. Ure upon the body of a murderer?

a very powerful battery was passed through portions of the body, all the motions of life were exhibited; laborious breathing commenced, the diaphragm rose and fell, the muscles of the countenance were simultaneously thrown into fearful action; rage, horror, despair, and ghastly smiles, united their hideous expression in the face of the lifeless murderer, while the arms and fingers exhibited convulsive movements, and seemed to point to the different spectators, some of whom believed life had returned.*

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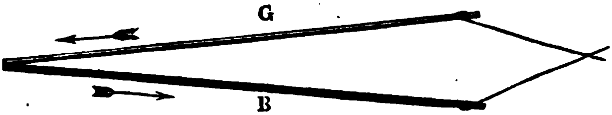
* Noad's Electricity.

THERMO-ELECTRICITY.

210. Professor Seebeck, of Berlin, in 1822, discovered that by joining two different metals, possessed of different conducting powers of heat, and heating these at the point of junction, a current of electricity would be caused to flow from the colder to the hotter metal. Electricity thus developed by the agency of heat is called *Thermo*-Electricity.

211. *Experiment.* — Let two strips, one of German silver, G, and the other of brass, B, Fig. 193, be brazed together, or merely touch each other at one of their extremities, and let them be so arranged as to form an acute angle, and have small copper wires attached to their free ends, as seen in the figure. Upon applying the heat of a spirit-lamp at the point of junction, a very perceptible current of electricity will flow from the German silver through the brass, whenever the copper wires are so connected as to form a complete circuit. The quantity of the electricity thus set free may be indicated by the deflection of the needle of the Galvanometer, Fig. 198, when the ends of the wires are made to connect with this instrument.

Fig. 193.



212. Two plates of German silver and antimony, heated, at the point of junction, by immersion in oil raised nearly to the melting-point of the latter metal, will set free electricity in greater quantity than any other combination of metals. Different degrees of temperature in the *same* metal will occa-

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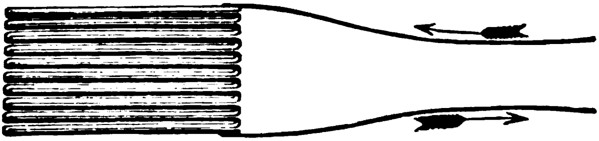
Define Thermo-Electricity. How may this be produced? How may the quantity of electricity set free by this process be indicated? What combination of metals, and how heated, to produce the greatest flow of thermo-electricity?

sion an electric flow from the colder to the warmer portion, which may be made perceptible, provided the metal be a poor conductor of heat, as in the case of platinum.

213. A thermo-electric battery of considerable power may be constructed, by soldering together alternate plates of German silver and brass or antimony, at such an angle as to allow the interposition of sheets of pasteboard, to prevent a contact of the metals, except at their ends or junctions. Such a battery is shown in Fig. 194. By the application of heat to such a series, an electric flow will take place proportioned to the number of the series and the degree of heat. Such an arrangement, formed by small bars of bismuth and antimony, becomes far more sensitive to the effects of heat than either the mercurial or air thermometer; so that even the radiant heat from the hand brought near one end of these bars, will excite sufficient electricity to deflect the needle of a delicate galvanometer several degrees.

Fig. 194.



The thermo-electric current thus excited between two different metals is referred to the difference in their conducting power for heat, and to the different orders of crystallization to which their particles belong; the laws of crystallization being supposed to result from the electrical character of the particles. This has not, however, been fully investigated, and many points are involved in great obscurity.*

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* Davis' Manual Magnetism.

Effect of different degrees of temperature in the same metal? How may a thermo-electric battery be formed? To what causes is the electric current, thus formed, referred?

ANIMAL ELECTRICITY.

214. THIS term is applied to that form of electricity produced by certain fishes, as a means of defence, or for the capture of their prey. Among these the Gymnotus, the Torpedo,* and the Silurus, are the most remarkable examples. These are each provided with a special set of organs for setting free electricity when desired for effecting a shock; and, although differing slightly in the form of the arrangement, yet, in the principle of their action, these organs are the same in each.

In the Gymnotus the electric organs consist of long membraneous structures, extending on each side of the spine from the head to the tail, and are divided by numerous septa into little cells filled with a gelatinous fluid for exciting electric action; thus bearing a striking analogy to the arrangement of the Compound Galvanic Battery. These organs are copiously supplied with nerves branching off from the spine, and appear to act through the nervous agency, subject to the control of the will of the animal; accordingly, if these nerves be severed, all power of the will over this galvanic arrangement ceases, the same as over the muscles of a limb when the nerves supplying them are cut.

215. The Gymnotus, or electric eel, is found in the waters of South America, and bears a strong resemblance to the common eel of this country; varying in length from two to five

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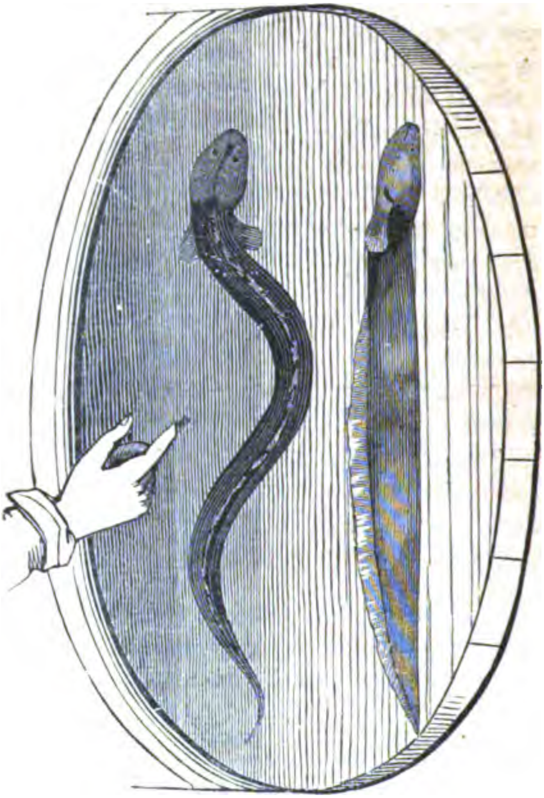
* The Torpedo is a flat fish, found along the shores of the Atlantic, varying in length from one and one half to four feet. Its electric organs are two in number, and lie one on each side of the head or gills. The electrified surface of these is very great, equivalent in some instances to a thousand feet of coated glass. When taken with a harpoon it sometimes transmits through this a severe shock to its captor.

Define Animal Electricity. What animals evolve this in the greatest degree? With what are these animals provided? The form of the electric organs of the Gymnotus? With what are these organs provided? Effect of severing these nerves? Where is the Gymnotus found?

feet. Fig. 195 presents views of this animal in two positions. The lower is a lateral view, and the upper a view from above. When disturbed by the entry of any animal into their watery realms, as a horse, for instance, these fishes glide along near or in contact with the body of the animal, and transmit a powerful shock, which, if repeated, may succeed in prostrating their victim. Humboldt relates seeing a herd of horses driven

Fig. 195.



Case of a herd of horses described by Humboldt?

into a pool, where were several of these gymnoti, and attacked by the latter with such vigorous shocks, as soon to be overpowered and made to sink powerless in the water; while, at the same time, the fish appeared to become exhausted as from a severe muscular effort.

A course of ingenious experiments with a Gymnotus was made some years since, by Dr. Faraday, whereby he proved the complete identity of this animal electricity with that evolved by artificial means; producing not only shocks, but decomposing and magnetic effects, the same as by the ordinary battery. In these discharges, the electric fluid passed from the head towards the tail; the former being the positive, and the latter the negative extremity of the animal battery.

216. Muscular action and animal electricity appear to be results of the same nervous or vital force, both alike requiring an expenditure of nervous energy for their production; so that whichever of these effects is produced, a proportional waste of the animal system results.

Leibig has accordingly suggested a theory of muscular action, which supposes that the contractile force of the muscles is due to a principle set free by the oxidizement of the animal tissues by the blood, in the same way that electricity is set free by the chemical action of acids on zinc. He supposes that, when muscular contraction takes place, the nerves supplying the part withdraw their vital protection, and oxidation under the chemical laws, and the consequent development of force, result. A further application of this theory would extend it to the electrical organs of fishes, where, by oxidizement of tissues suitably arranged, electricity itself, instead of muscular force, would be eliminated whenever the protecting agency of the nervous system was withdrawn.*

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* Davis' Manual.

What did Dr. Faraday's experiments upon the Gymnotus prove? What is said in regard to muscular action and animal electricity? Theory of Leibig.

217. During certain diseases of the nervous system the human subject has been known to emit electric shocks. In such cases the nervous energy, as in the Gymnotus, seems directed to the production of electrical instead of muscular force, as in ordinary states of the system. Free electricity is found to be an invariable result of chemical change; consequently, the animal body, which is subject to constant and extensive changes of this nature, is found to set free large quantities of electricity. Now, if in certain abnormal states this be subject to the control of the will, acting through the nervous agency, as we have supposed, may we not reasonably infer that animal electricity exerts in some way an agency for producing the mysterious phenomena exhibited in the movements of inanimate matter in certain relations to the human subject?

Matteucci found, by experiment, that currents of electricity were constantly passing between different parts of the living body. Thus, by making a metallic communication between the liver and stomach of a live rabbit, he found a powerful galvanic current setting from the one organ towards the other. Hence, some distinguished physiologists have been led to ascribe to electricity an important agency in digestion, and the secretions of the animal body. However this may be, there can be but little doubt that electricity plays an important part in the economy of the animal system, which science may sooner or later unfold more fully to our understanding.

Case in certain diseases of the nervous system? Effect of chemical changes in the animal system? What did the experiments of Matteucci show? What agency is ascribed to electricity by some distinguished physiologists?

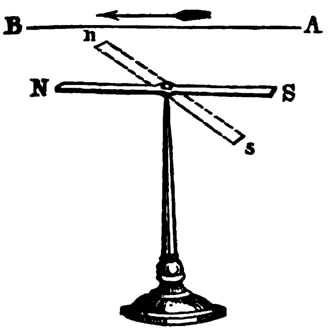
ELECTRO-MAGNETISM.

218. The influence of electricity in communicating Magnetism to bars of iron and steel, and also in destroying or reversing the polarity of the magnet, has been known for ages; but not until the discovery by Professor Oersted, of Copenhagen, in 1819, was the power of an electric current, in giving *direction* to a magnet, or the peculiar reciprocal force between this and the magnet, known.

219. *Electric currents exert a magnetic influence at right angles with the direction of their flow.* — If the wire conveying a galvanic current be made to pass near a nicely balanced bar-magnet, lying in the same direction, this will be at once deflected, and made to take a position at, or approaching to, a right angle with the wire.

Thus, in Fig. 196, let A B represent such a wire, and S N a magnetized bar lying directly beneath and in the same direction with the wire. Upon the passage of an electric current the magnet is at once deflected, and tends to a position, s n, at right angles with the wire. Place the wire as before, but *beneath* the magnet, and allow the electric current to flow through it in the same direction as when placed above; the magnet will be at once reversed,

Fig. 196.

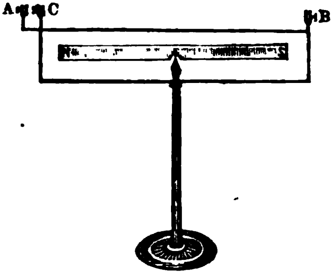


What is said of former knowledge in respect to the influence of the electric current in communicating Magnetism? In what direction do electric currents exert their magnetic influence? State the effects of such a current when passing along a wire near a nicely balanced bar-magnet lying in the same direction. Effect of so bending the wire as to send the current around the magnet?

S standing where N, and N where S did previously. If the wire be bent, so as to convey the current around the magnet above and below in opposite directions, these opposite currents will exert upon the magnet forces auxiliary rather than antagonistic to each other.

220. The *Galvanometer*, Fig. 197, designed for measuring the quantity of an electric current, will serve to illustrate this more clearly. The instrument shown in the figure consists of a single wire, bent at right angles so as to pass above and below a nicely balanced magnet, N S; the point where the parts of the wire pass each other near C, being insulated by winding with a little thread.

Fig. 197.



Attach the wires of a galvanic battery to the screw-cups, A and B, so that electricity shall flow through only the portion of the wire upon the upper side of the magnet; this will be deflected to a certain extent. Let the connection now be made at A and C, so as to send the current above and below the magnet in opposite directions. A much greater deflection than before will take place.

If, instead of a single turn, as in this case, the wire be carried several times around the magnet, the magnetic force exerted by a current of electricity traversing this will be increased in proportion to the number of these turns, within certain limits. Galvanometers thus constructed are termed *multipliers*, since they serve to increase the power of the electric current, and indicate its flow even in the smallest quantities.

Design of the Galvanometer, Fig. 197? Effects of the galvanic flow through only the upper side of the wire surrounding it? Through the entire wire? Effect of the galvanic flow through a wire making several turns about the magnet? What are galvanometers thus constructed called, and why?

Fig. 198.

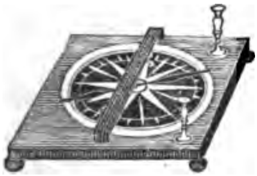
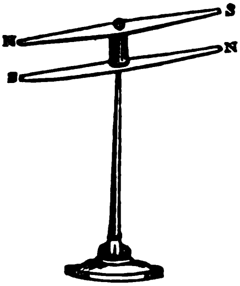


Fig. 198 shows a common form of the Galvanometer for indicating the direction and quantity of the galvanic flow. A wire is coiled several times about a magnetic needle, with its two ends terminating beneath the screw-cups. The needle is made to stand in a line with the coil when acted upon by the earth's magnetism alone. Upon the passage of an electric current, this is deflected to a greater or less angle, varying with the quantity of the flow; the amount of these deflections being indicated by a graduated card pasted on the stand beneath. Thus, by means of the Galvanometer properly constructed, currents of electricity, by far too feeble to be detected by ordinary means, may be made to affect sensibly a magnetic needle.

221. As the magnetic attraction exerted by the earth affects somewhat the sensitiveness of the needle to electric influences, Nobili devised the *Astatic Needle*, for obviating this difficulty. This is seen in Fig. 199, and consists of two similar magnetic needles, placed one above the other in positions the reverse of each other in respect to their poles. Thus, its directive tendency in respect to the earth is neutralized, so as to allow it to remain at rest in any position, and so rendering the influence of the galvanic flow more perceptible.

Fig. 199.



222. The poles of a magnet, as has been already shown, observe certain invariable positions, in reference to the direction of the electric current. In order to impress on the memory these positions, Ampere has suggested the following formula: *Let the person suppose himself lying on the wire with his*

What does Fig. 198 represent? Describe the Astatic Needle. State the formula of Ampere.

face towards the magnet, and the electric current flowing from his head toward his feet; the north pole of the magnet will always be toward the right hand. By bearing in mind this simple rule, the direction of the flow of an electric current may be always readily determined, upon observing the position of the poles of a magnetic needle in reference to it.

Thus, from what has been said, it will be seen that, unlike all other motive powers in nature, electricity exerts its magnetic force *laterally*, instead of in the line of its direction. Nor does the magnetic pole move either directly towards or directly from the conducting wire, but tends to revolve around it without changing its distance. Hence, the force exerted upon the magnet must be considered as acting in the direction of a *tangent* to the circle in which the magnetic pole would move.*

In the illustrations we have given, the action of the electric current has been exerted alike on both poles of the magnet in contrary directions, causing these to assume a state of equilibrium in a direction transverse to the path of the current or wire conveying it.

223. *If the conducting wire of an electric current be made to pass near a single pole of a magnet free to move, this pole will commence a revolution around the wire in a direction depending on the course of the current.* — Thus, if the north pole of a magnet be presented to a vertical wire, through which a stream of electricity is *descending*, it will, if free to move, revolve about the wire in the direction of the hands of a watch. If the current be made to *ascend*, the pole will take an opposite direction. With the *south* pole thus situated, the direction of the motion will be reversed.

These movements of a single magnetic pole about a con-

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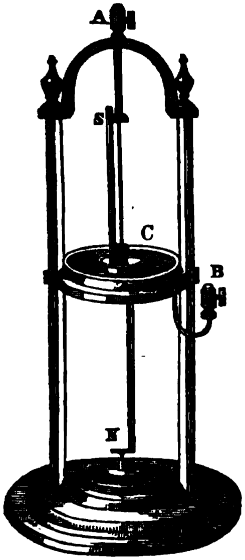
* Davis' Manual.

What is said in regard to the direction in which the electric current exerts its magnetic force? Is the direction of this the same as other forces? State the proposition. Illustrate this.

ducting wire may be illustrated by an arrangement shown in Fig. 200. A magnetized bar, S N, bent at right angles in its middle, rests on an agate, or other insulating support, at N. A vertical wire is fixed in the axis of motion, to which the upper pole, S, is so attached by a small loop as to allow the magnet to revolve freely about it. This wire, connecting with the screw-cup, A, has its lower extremity resting in a small cup, placed upon the horizontal portion of the magnet. From this cup projects a wire, bent so as to terminate in a circular cistern of mercury, open in its centre to allow a revolution of the magnet, independent of any contact with it. With this mercury-cistern is connected a second screw-cup, B.

Fig. 200.



Experiment.— Attach the positive pole of a galvanic battery at A, and the negative at B; the galvanic current will flow down the vertical wire, near the upper pole, S, of the magnet, and pass off at C, through the bent wire and mercury, to B. Thus, as but a single pole of the magnet is acted on, it will commence a rapid revolution round the conducting wire, in the direction and according to principles already stated.

As action and reäction (§ 20) are always equal, if the conditions of the magnet and the conducting wire in this experiment be changed, so that the former shall be permanent, and the latter free to move, upon transmitting a galvanic current

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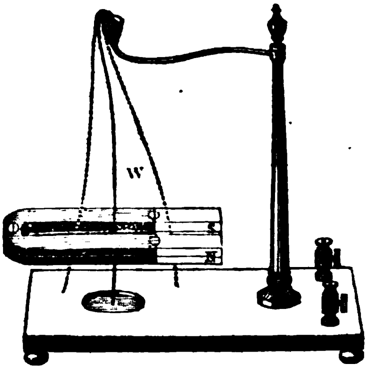
What does Fig. 200 illustrate? Explain this instrument. How will the passage of the electric current along the wire, near the upper pole of the magnet, affect it? Result of changing the conditions of the wire and magnet in this experiment?

through the wire, this will be made to revolve about the magnet, the same as the magnet about this in the experiment.

224. *If a conducting wire, free to move, be submitted to the action of* BOTH *poles of a magnet, it will move forward in a line between these two poles.*

This may be shown by the arrangement seen in Fig. 201. From a small mercury-cup, at the end of a horizontal rod attached to an upright post, is suspended a copper wire, W, with its lower extremity, when at rest, just entering a small basin of mercury in the stand. The wire hangs so as to vibrate freely between the two poles, N S, of the magnet. Two screw-cups upon the stand communicate, one with the cup which supports the wire, and the other with the mercury-basin.

Fig. 201.

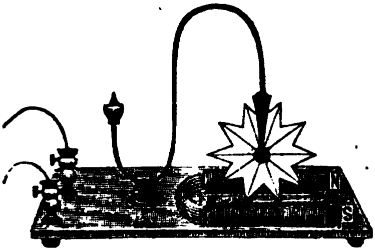


Experiment. — Connect the screw-cups with the battery, so as to cause a galvanic current to traverse the wire, W. This will be attracted alike by the two poles of the magnet, and as it can revolve around neither, owing to the counter attraction of the opposite pole, it will be driven forward or backward, according to the direction of the current, in a straight line between the two forces, to the positions indicated by the dotted lines; and, upon leaving the mercury, the circuit will be broken, causing the wire to fall by its own weight back again into it, so as again to renew the circuit, and be again attracted. Thus, a vibratory motion of the wire will be maintained as often as it becomes the path of the galvanic flow.

Effect of submitting the conducting wire to the action of both poles of a magnet? Explain Fig. 201. Why does the wire continue to vibrate?

Experiment a. — A more interesting form of the last experiment may be shown by the *Revolving Spur-Wheel*, Fig. 202, where the vibratory movement is converted into one of rotation. Instead of a wire, as in the previous experiment, a spur wheel is so suspended between the poles of a magnet, or electro-magnet, that its points shall enter successively a small basin of mercury arranged on the stand, as in Fig. 202.

Fig. 202



Thus, during the passage of the galvanic current, each point becomes a conductor, and under the influence of the magnetic poles is driven forward and out of the mercury, just as the next succeeding one enters, and so causing the wheel to rotate, on the same principle that the wire in the last experiment was made to vibrate.*

225. *If an electric current be made to traverse a coil of wire free to move, this coil will arrange itself at right angles with the poles of the earth, or those of an artificial magnet.* — As action and rëaction between the electric current and magnet are equal, when the latter is permanent, the wire conveying the former, if free to move, will arrange itself at right angles with the *polar axis* of the magnet.

The position of such a coil, in reference to the earth's

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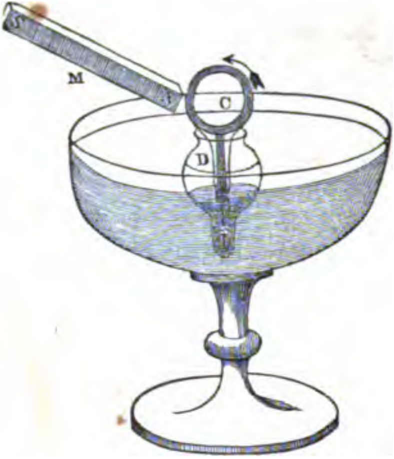
* As the points successively leave the mercury, and so break the galvanic circuit, if in a dark room, sparks will be seen at the point of rupture, and, if these be repeated with sufficient frequency, by an optical illusion the wheel will appear nearly at rest. If, instead of the spur-wheel, an entire disc of metal be substituted, its revolution will be the same except more uniform.

What results when the electric current is made to traverse a coil of wire free to move?

magnetic poles, may be illustrated by the arrangement seen in Fig. 203, and known as *De La Rive's Ring.* This consists of a compact coil of insulated wire, C, with its two ends attached to small plates of zinc and copper, Z, C. The coil with its plates rests in a glass cup, D, into which is poured sufficient dilute acid, to cover the plates; and the whole is allowed to float in a basin of water. The action of the acid on the metals will set free a current of electricity; and this, flowing through the coil, will cause it to assume a definite position at right angles with the earth's magnetic axis, as previously stated.

Fig. 203.



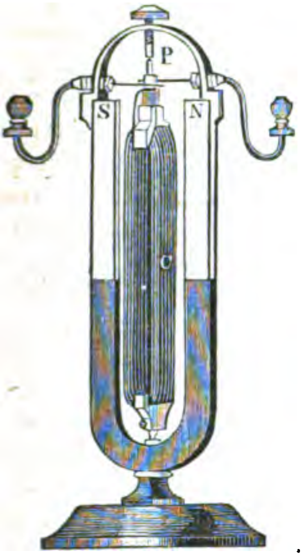
Thus, the two faces of the coil will take opposite polarities, like a magnet. If, while in this condition, the north pole of a magnet be presented to the south polar face of the coil, a mutual attraction will be exerted, as between the opposite poles of two magnets, and vice versa.

226. The polarity produced in a wire coil by the flow of a galvanic current through it may be shown by the *Revolving Rectangle*, Fig. 204.

Here, a rectangular coil, C, is arranged in a vertical position, so as to revolve freely on two points between the poles of a U-magnet.

Describe De La Rive's Ring. Effect of a galvanic flow through the coil while floating on the water? While the ring is in this condition, what results if the pole of a magnet be presented? What does the Revolving Rectangle show? How is this arranged?

Fig. 204



By means of the *Pole-Changer*,* at P, the direction of the current traversing the wire-coil is twice changed during each revolution, and thus twice changing the polarity of the coil. These changes happen at the moment when its axis is passing between the poles of the magnet, so that the condition of the wire in reference to the poles of the magnet causes it to undergo a constant series of attractions and repulsions just at those points where force is most needed to give it motion.

Experiment. — Connect the Revolving Rectangle, Fig. 204, with a Sulphate of Copper Battery, and, cause a galvanic flow through the wire-coil. This will immediately commence a rapid revolution, at a speed of from five to ten thousand turns in a minute; showing the wonderful rapidity

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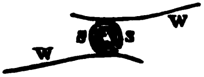
* The *Pole-Changer* attached to the coil may be illustrated by Fig. 205. This consists of two small semi-cylindrical pieces of silver, S S, fixed on the opposite sides of the axis of motion, A, but insulated from that and from each other; to each of these segments is soldered one end of the wire composing the coil. The battery wires are terminated by horizontal portions of flattened silver wire, W W, which press slightly on opposite sides of the pole-changer, and must be so arranged, that the direction of the current flowing through the coil shall be reversed at the moment when its axis is passing between the poles of the magnet.—(*Davis' Manual Mag.*)

Fig. 205.

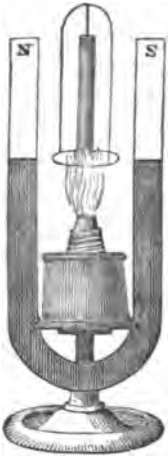


State how the galvanic current flows through this so as to produce rapid motion. State the experiment with this.

with which electricity traverses the coil, in twice changing its direction during each revolution.

227. We have already spoken of *thermo-electricity*, or that form evolved by the action of heat on two different metals (§ 211). This is subject to the same magnetic reäctions as galvanic electricity, which may be illustrated by the *Thermo-Electric Arch*, Fig. 206. This consists of a wire arch, mounted on a brass pillar, between the poles of a U-magnet. The lower or circular portion is of German silver, the upper of brass or iron. Upon a movable stand in front of the brass pillar is placed a lamp for heating the metals.

Fig. 206.



Experiment. Apply the heat of a spirit-lamp to one of the junctions of the wires. A current of electricity will be made to flow from the German silver to the silver, passing up the heated side of the arch, and down the other, thus performing an electric circuit through this. This gives polarity to the wire, the same as to the coil, in Fig. 203, that face presented to the north pole of the magnet acquiring north polarity, and that to the south pole, south polarity. Repulsion of these, like poles and attraction between the unlike, causes the wire-arch to revolve half way round, which brings the other junction within the flame; the current is now reversed, and the face towards the north pole of the magnet acquires north polarity, and is again driven through a semi-revolution; thus a constant reversion of the electric current, flowing through the arch, causes it to be alternately repelled and attracted by the magnetic poles, and made to revolve. By placing the lamp on the

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Describe the Thermo-Electric Arch. State the experiments with this.

opposite side of the magnet, the direction of the current will be such that the south pole of the arch will be presented to the north pole of the magnet, and no revolution, consequently, is produced.

228. *Ampere's Theory of Magnetism.* — From these, and a great variety of kindred illustrations, Ampere has deduced a theory, which supposes all magnetic phenomena to be produced by electric currents. Thus, every molecule of a magnet is supposed to have a current of electricity perpetually circulating around it. The only difference between a magnet and a mere bar of iron consisting in the fact that, in the former, electricity is in a state of constant action around each ultimate particle of iron; while, in the latter, this is in a quiescent or latent state. The resultant of these numerous little circuits in a magnet is the same as that of the electric current traversing a wire-coil surrounding a bar of iron, as seen in Fig. 208. When the currents of electricity in different circuits move in the same direction they attract each other (§ 220), and, when in opposite directions, they repel. Hence, if the *unlike* poles of two magnets be placed end to end, the electric currents of each will be found moving the same way; those of the north pole being but a continuation of those of the other, and thus the two poles will be drawn together; while, if the ends of *like* poles be presented, the course of the currents traversing each will be in opposite directions, and a repulsion will result. A magnetic needle tends to arrange itself at right angles with a wire transmitting an electric current, in order to bring the numerous currents circulating around its particles parallel with that of the wire.

229. *The magnetism of the earth* is also explained, according to the theory of Ampere, by supposing the existence

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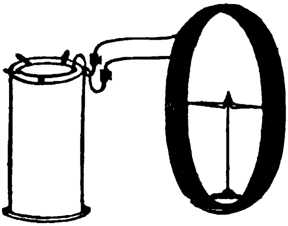
What does Ampere's theory of magnetism suppose? Difference between a magnet and a mere bar of iron? What is said of currents of electricity moving in the same and in an opposite direction? Why does a magnetic needle tend to arrange itself at right angles with the electric current? How is the earth's magnetism explained by the theory of Ampere?

of currents of electricity constantly traversing it near its surface, from east to west, in a direction at right angles with a line joining the magnetic poles. These currents are regarded as thermo-electric, and produced by the action of the sun's heat in his daily circuit. The action of such a current in inducing magnetism, and giving direction to a magnet, may be shown by the *Terrestrial Helix*, Fig. 207. If an electric current be made to circulate through this coil in the same direction as about the earth, its action upon a magnetic needle will be similar to that of the earth, causing the needle, when standing directly over the coil, to maintain a horizontal position to the axis, and to vary from this when carried towards the imaginary pole of a sphere, of which the coil represents the equator, the same as seen in Fig. 128.

Fig 207.



230. As we have already shown, temporary magnetism may be imparted to soft iron, by contact with a magnet; we come now to speak of the manner of effecting the same by electricity.

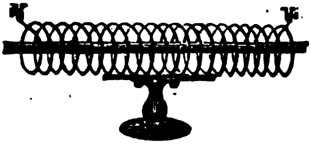
If a current of electricity be made to circulate around a bar of soft iron, it will render this magnetic so long as the current continues to flow. — The magnetic action of an electric current on a bar of iron varies with the number of revolutions it performs about this. Thus, a single turn affects the magnetic needle, in Fig. 197, much more than the passage of the electric current on only one side of this; so, by increasing the number of the turns of the conducting wire, the power of the current, in inducing magnetic properties in the iron, will be proportionably increased.

Experiment. — Let an insulated copper wire, loosely coiled,

Effect of an electric current flowing around a bar of soft iron? Effect on the magnetism of the bar by increasing the number of the turns of the wire?

as seen in Fig. 208, be made the conducting medium of a galvanic flow, and place within it a rod of soft iron. This rod will become instantly magnetic so soon as connection is made with the battery, having a north and south polarity, like a common magnet. Such is termed an *Electro-Magnet.*

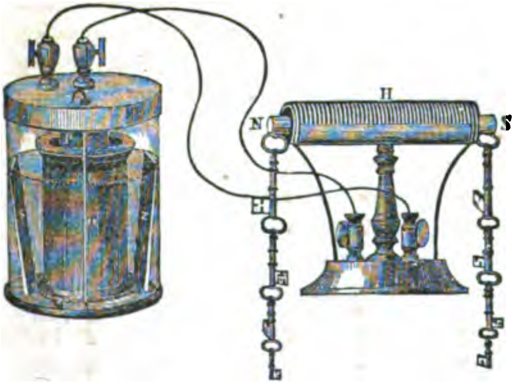
Fig. 208.



231. Soft iron, in such a position, instantaneously acquires and loses its magnetism whenever connection with the battery is made and broken. Hardened steel becomes less readily magnetic, but retains its magnetism after the current ceases to flow.

Experiment. — With a larger and more compact coil or helix, magnetic effects may be produced much more striking. Fig. 209 shows such a magnetizing helix. A compact coil of insulated copper wire is mounted on a stand, with its two ends terminating in the bottom of the screw-cups. Connect the

Fig. 209.

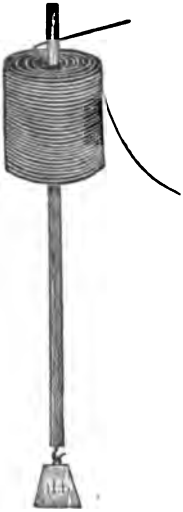


Effect on soft iron in such a position? On hardened steel? Explain Fig. 209.

poles of the battery with the screw-cups upon the stand beneath, so as to cause the electric current to traverse the wire-helix, H, and a rod of soft iron placed within this will become instantly powerfully magnetic. This may be shown by attaching metallic bodies to its ends, as shown in the cut. The moment the flow of the current is interrupted by raising one of the polar wires of the battery slightly from the screw-cup, the iron rod ceases to be a magnet, and the suspended bodies fall.

232. The wonderful effects of the electric current, in developing magnetic power in small rods of iron, may be shown by the *Magnetizing Helix*, Fig. 210. This consists of a considerable extent of wire, wound into a compact coil, with a small hole opening through the centre.

Fig. 210.



Experiment. — Connect the ends of the wire with a battery producing a large flow of electricity,* and, with the helix in a perpendicular position, as shown in the cut, drop through the opening a small iron tube or rod. This will become strongly magnetic, and be sustained within the coil *without any visible support*, owing to the force with which it is drawn towards the middle of the coil by the opposite attractions. If the battery and helix be of sufficient size, a considerable weight may be suspended, as shown by the figure.

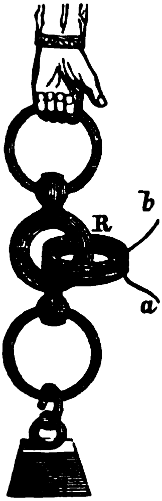
Such a helix, employed by Dr. Page in a lecture at the Smithsonian Institute, a few

* The power of a common Pot Battery is insufficient to cause this experiment to succeed. A battery of much greater magnetic force, as the Trough Battery or Grove's, should be employed.

Design of the Magnetizing Helix seen in Fig. 210? Give the experiment with this.

years since, was able to raise and suspend, free from any contact, a bar of iron which weighed *eighty* pounds.

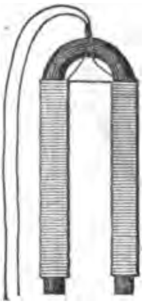
Fig. 211.



233. The induced magnetism of an electric current may be again shown by the wire coil, R, Fig. 211, and the semi-circles passing within this coil. These semi-circles are of soft iron, with faces evenly fitting to each other, and are provided with strong handles or rings.

Experiment. — Connect the wires *b* and *a* with a Sulphate of Copper Battery, and then bring together the semi-circles, as shown in the figure. These, with a battery of medium size, will be held together with a prodigious force, sustaining a weight of more than a hundred pounds. After breaking the flow of the current, they adhere slightly, but, lose entirely their magnetism when once separated.

Fig. 212.



234. An *electro-magnet* of great power may be made, by bending a round bar of soft iron, as shown in Fig. 212, and winding the arms with two or three layers of insulated copper wire.* When this wire is traversed by the electric current, such a magnet becomes far more powerful than an ordinary steel magnet of equal size. The power of such a magnet

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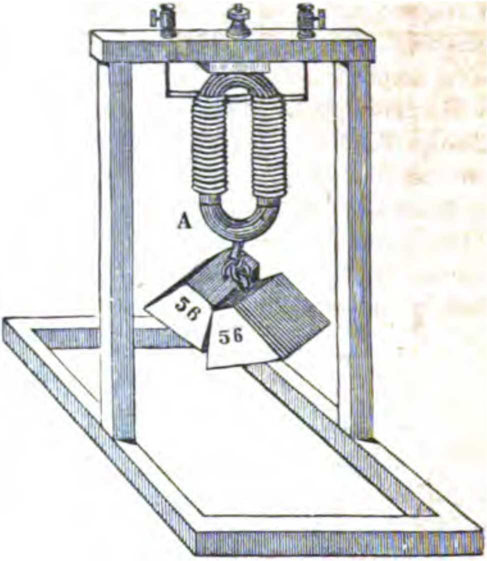
* The magnetic power of the electro-magnet depends on the number of turns the wire takes around the bar; thus, a small magnet, closely wound with fine copper wire, may be rendered far more powerful than a larger bar loosely wound with a coarse wire. The former magnets are used for telegraphs, shocking-machines, etc.

Explain Fig. 211. Give the experiment. How may an electro-magnet of great power be formed?

may be shown by the arrangement seen in Fig. 213, where the electro-magnet is fixed in a frame, and provided with a semi-circular armature, A, to which the weights to be suspended are attached whenever communication is made with the battery. This armature will be attracted to the magnet with a force sufficient to support a surprising weight.

Fig. 213.



235. *Electro-Magnetic Telegraph.*—Among the wonderful triumphs which science and art have achieved within the past few years, few hold so important a rank as the Electric Telegraph. For half a century previous to its application by Professor Morse, efforts were made from time to time to effect distant and rapid communications of thought by means of electricity. In the earliest of these experiments the common Electric Machine was employed, and afterwards the Galvanic

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Explain Fig. 213. What is said of the Electro-Magnetic Telegraph? What was used for producing the electric current in the earliest experiments?

Battery. By means of these, decomposition of water and various chemical compounds were attempted for signals. The deflection of the magnetic needle was afterwards suggested by Ampere, and, in 1837, introduced into practice on a large scale, by Wheatstone, in England. All these various devices for telegraphing, by means of electricity, yielded, however, to the beautiful simplicity and efficiency of the American Electro-Magnetic Telegraph, which is claimed to have been suggested by Dr. Charles T. Jackson and Professor Morse, in 1832, but was matured and practically introduced by the latter, between Baltimore and Washington, in 1844.

236. The following description of Morse's Telegraph, abridged from Davis' Book of the Telegraph, will aid in comprehending the general operation of this wonderful contrivance.

Fig. 214.

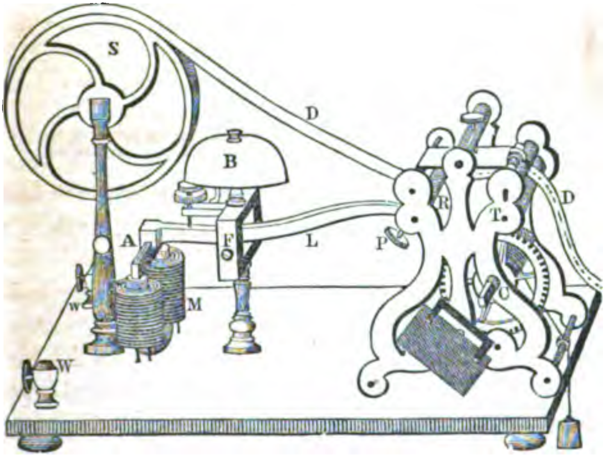

Fig. 214 shows the registering portion of the Electro-Mag-

What afterwards? What did Ampere suggest for giving signals? What is said of Morse's discovery? Describe the parts of Morse's registering apparatus, shown in Fig. 214.

netic Telegraph, along with the appendages usually employed. M is the electro-magnet, the wires of which connect with the two screw-cups, W w, upon the end of the stand.* L is the lever playing over the fulcrum, F, having an armature, A, at one end, near the poles of the magnet, while, at the other, is a blunt point, P, which strikes up against the roll, R, under which the strip of paper passes, and so marks it whenever the electro-magnet is in operation. This strip of paper, D D, is gradually drawn off from the spool, S, by means of two tight rollers at T, between which it passes. These rollers are moved by a clock-work arrangement beneath, at C, which is set in motion by the first movement of the lever. A bell, seen at B, is connected with the lever, so that upon the first motion communicated by the battery, this is struck, and a signal thus given to the attendant.

The battery by which the register is worked may be twenty, fifty, or a hundred or more miles distant, provided, it be of sufficient power, and the wires conveying the electric current properly insulated.† These wires are attached to the screw-cups, W w, of this register, causing the coil around the arm of the magnet, M, to form part of the circuit between the two poles of the battery. Thus, whenever the battery is in operation, and the circuit between its two poles complete, the electro-magnet, M, instantly becomes powerfully magnetic, and attracts the armature. This causes the point, P, to strike up against the paper, and leave a dot or a mark, varying in length according to the time the current is allowed to pass, and the armature to be attracted. Fig. 215 shows a more modern and convenient form of the Telegraph Register, and one which is now generally used with Morse's lines.*

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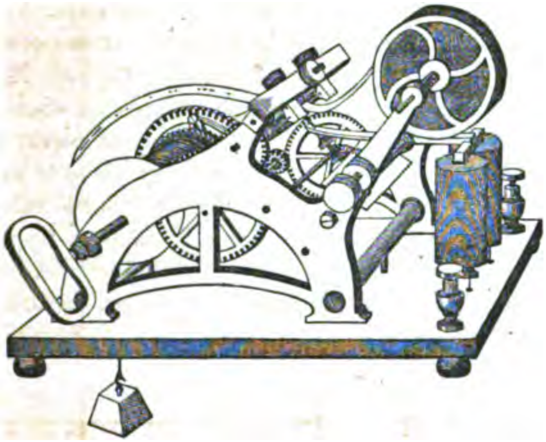
* This electro-magnet is wound with very fine copper wire, and contains usually some three thousand feet of this. In this way great power is given to the magnet, without rendering it of an inconvenient size.

† Grove's Battery has been more generally used for working the telegraph; about thirty cups being required for a distance of 150 miles. These cups may be kept in one compact space, but operate the telegraph more successfully when distributed along the line. Such batteries will work for about two weeks without replenishing. Various other forms of batteries are adopted, as Bunsen's Charcoal, Daniell's Self-protecting, etc. Telegraphs, in some instances, are said to have been worked by the action of moist earth on metallic plates buried in it.

Fig. 215.



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* The signs employed by Professor Morse are the following: These dots and marks are used to represent the various letters expressing the words or sentence transmitted:

ALPHABET.		*n*	— -		
a	- —	*o*	- -	NUMERALS.	
b	— - - -	*p*	- - - - -		
c	- - -	*q*	- - — -	1	- — — -
d	— - -	*r*	- - -	2	- - — - -
e	-	*s*	- - -	3	- - - — -
f	- — -	*t*	—	4	- - - - —
g	— —	*u*	- - —	5	— — —
h	- - - -	*v*	- - - —	6	- - - - - -
i	- -	*w*	- — —	7	— — - -
j	— - — -	*x*	- — - -	8	— - - - -
k	— - —	*y*	- - - -	9	— - - —
l	——	*z*	- - - -	0	———
m	— —	&	- - - -		

This combination of lines and dots is arbitrary, and may be changed at any time by an agreement between the telegraph operators.

What is said of the battery by which the register is worked?

The simplicity of the arrangement of the Morse telegraphic machines gives them some important advantages over other more ingenious and complicated forms described in the subsequent pages; and hence their extensive introduction. Already these lines upon this continent extend over an aggregate distance of fifty thousand miles, and transmit, with the lightning's speed, messages throughout the length and breadth of the land.

No recent invention has done more than the electric telegraph to smooth the asperities which often exist between sections widely remote, and strengthen the bonds of social union; and to the discoverers of this wonderful method of communication between distant cities, states and continents, civilization and Christian philanthropy may look as to important aids in their onward progress.*

Baine's Chemical Telegraph. — This differs from Morse's, just described, chiefly in the manner by which the message is registered, this being effected by the decomposition of a chemical solution spread upon paper, which covers a circular tablet. This tablet is made to revolve by clock-work, while an iron pen or point writes in lines and dots the messages in spiral curves upon the paper of the tablet.† By means of the machines employed with this telegraph, messages may be transmitted with a rapidity considerably exceeding that of Morse's lines.

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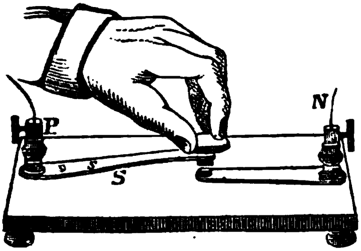
* An ingenious application of the telegraph has been recently made to railway trains, by means of a battery and registering apparatus placed in these. A spring extending down from the register and battery bears gently upon an insulated wire, or other metal, laid between the rails, and thus an electric communication is afforded between the train and a distant railroad station, or between two trains. In this way an alarm may be given to or from a train in motion at any point on the road.

† Experienced operators of this as well as Morse's machines often dispense with the paper altogether, writing the messages directly out from the sound of the clicks upon the plate or cylinder.

What is the extent of these telegraph lines in this country? What results has the invention of the Electric Telegraph tended to bring about? What is said of Baine's Chemical Telegraph?

237. The *Signal-key* or *Break-piece*, Fig. 216, is the instrument usually employed for interrupting the current and regulating the system of lines and dots. This is placed near the battery, so as to be in the galvanic circuit. One wire from the battery entering the screw-cup, P, while the other screw-cup, N, receives the wire of the telegraph which leads to the registering apparatus at the remote station. By pressing upon the knob attached to the spring, S, a connection is formed between P and N, and the electric current allowed to pass to the register, from whence it is returned to the battery again by a second telegraph wire. Thus the circuit is completed by depressing the spring, and broken again by the action of this when the fingers cease to press upon it.

Fig. 216.



238. Instead of a second wire, directly connecting the register and battery, the earth is more generally employed as a conductor, by connecting the pole of the battery and register with a large metallic plate sunk in the ground at each terminus of the telegraph. In this case but a single wire is needed.*

When the distance between the stations is great, the power of the electric current, owing to the imperfect insulation of the

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* These wires are more generally carried along lines of railroads, between distant points, and are elevated on strong poles above the danger of ordinary accident. A glass or stone ware support serves to insulate the wire where it rests upon the poles. In Paris, and other European cities, these telegraphic wires are enclosed in insulating tubes of gutta-percha, and laid under ground, thus rendering them less liable to accident, or to disturbances from changes of the atmosphere.

Use of the Signal-key or Break-piece, Fig. 216? How is this used in operating the register? Is it necessary that there be two wires for completing the circuit between distant stations?

wires, often becomes too feeble to operate successfully the registering apparatus.* To remedy this defect, Professor Morse devised an arrangement called the *Receiving Magnet*, whereby a second battery, placed in the circuit at the distant station, is made to operate the register in the same manner as the first battery would do at a less distance.†

239. *House's Printing Telegraph.* — This affords one of the most remarkable exhibitions of mechanical skill on record, and reflects the highest credit upon the inventive genius of Mr. Royal E. House, its distinguished, yet modest and unpretending discoverer. This telegraph is operated by the agencies of electricity and condensed air; the former being required to compose and the latter to print the message transmitted. The constituent parts of this telegraph, as presented from an exter-

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* The *Hughes' Telegraph* is an instrument recently patented by Mr. David E. Hughes, of Kentucky. This, like the House machine, prints the messages, employing for this, however, in place of the condensed air, an electro-magnet. The proprietors of this telegraph claim for it many advantages over those previously invented. Among these may be stated the following: *First*, that the machine prints with greater rapidity, being capable of doing this as fast as the most expert operator can touch the proper keys of the letter-board. Second, that it allows of a self-locking of the machines intermediate between two principal stations, so as to transmit a message direct, as from Washington to Boston. Third, that it admits of transmitting messages in all states of the atmosphere. And, finally, that messages may be transmitted upon the *same wire*, in opposite directions, at the *same moment*. With a proper insulation it is said that a single battery will operate these machines at a distance of five thousand miles.

We have recently examined a telegraphic machine, invented by Moses G. Farmer, Esq., telegraph engineer of this city, which, in point of simplicity of operation and cheapness of construction, commends itself most favorably to our judgment. This machine prints plain Roman capitals, and may be operated by an inexperienced person — the only requisite being an ability to read and spell.

† Improvements in telegraphic apparatus now enable batteries to operate at very great distances. A project is now on foot for extending a submarine telegraph across the Atlantic Ocean, from Ireland to Newfoundland, a distance of 1680 miles. Another telegraphic line is about to be extended from

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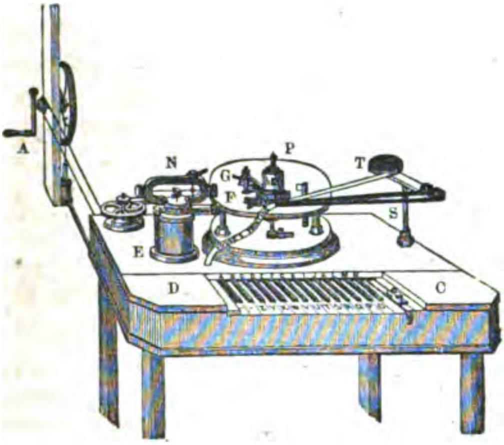
What is said of House's Printing Telegraph? By what agencies operated?

nal view, are shown by Fig. 217; this view can give the learner only a very general idea of its construction and operation.

240. The *composing machine* is arranged within a mahogany case, C, while the *printing* arrangement stands upon this, and both are operated by turning a crank at A, or by a foot-power and treadle placed beneath the frame. At the front part of the case is a key-board provided with twenty-eight keys resembling those of a piano; on these keys are marked the letters of the alphabet and also a dot and a dash. Beneath the key-board revolves an insulated iron shaft, surrounding which is a cylinder provided with two spiral lines of points projecting up from its surface; this cylinder revolves with the iron shaft passing through its centre, by means of a friction spring, and when pressed upon by a slight force may be stopped, while the shaft continues to revolve.

Fig. 217



London across the Mediterranean Sea, into Africa; also to Greece, Constantinople, India, and so across to Australia. Thus we may soon expect a telegraphic communication to be formed with the distant regions of Asia and Polynesia, whereby messages shall be received from these opposite quarters of the globe in the space of a few minutes or hours at most.

To the end of this cylinder, beneath C, is attached a brass break-wheel, having fourteen teeth and as many intervening spaces; upon these teeth strikes a spring, which connects with one of the battery-wires leading off to the distant station; the other battery-wire passes from the magnetizing helix in the upright cylinder at E, and connects with the iron shaft at the end beneath D, thus causing this and the break-wheel to lie in the electric circuit.

As the cylinder revolves, the current is rapidly interrupted by the spring and break-wheel, and the electric pulsations transmitted and made to give a corresponding revolution to a type-wheel of the machine at the remote station. When a key is depressed, it catches the pin upon the cylinder, as it comes round beneath, and so stops the motion of this until the letter upon the remote type-wheel corresponding with that upon the key is printed; this is then released, and another key depressed, which in like manner stops the cylinder until its letter is also printed; and so the process goes on, the letters of the words of the message transmitted being rapidly printed at the remote station in plain Roman capitals, at the rate of two hundred and fifty or three hundred per minute.

241. *The Printing Machine.* — This stands upon the mahogany case above the composing apparatus, and is worked by a manual power at A, independent of electricity. The variety of the parts composing this machine will allow of only a general description from a single figure, and the brief limits here assigned to this subject.

Below the small dome, at P, is the escapement-wheel. This is a steel wheel about two inches in diameter, and revolves with the vertical shaft passing through the circular iron plate, by means of a friction arrangement. This escapement-wheel may be stopped, while the shaft to which it is attached continues to revolve. Upon the lower circumference of this wheel are fourteen teeth, corresponding with those upon the break-wheel of the composing machine; upon these teeth play the pallets of an escapement, F, having the end of its lever connected with the piston-rod of an air-cylinder placed beneath the circular plate at F. As this piston-rod moves once back and forth, it causes the escapement to vibrate and allow a tooth of the wheel to escape; thus giving to this wheel a motion corresponding to that of the break-wheel of the cylinder below. Around the circumference of the escapement-wheel, above the escapement, are twenty-eight equi-distant projections, on which are engraved in order the alphabet, a dot, and a dash. This wheel, accordingly, advances one letter at each vibration of the escapement.

Within the upright cylinder, at E, is a magnetizing helix placed in the electric circuit; in this helix are fixed several separate annular electro-magnets, which act upon corresponding armatures, fixed upon a rod supported at its upper extremity by a horizontal spring passing across the elliptical ring, N, above the cylinder. As the electric current passes, the annular magnets within the helix become charged, and draw down the armatures and rod; this opens a valve connecting with the upper portion of the rod, and admits the air from an air-chamber below to the cylinder which works the escapement. Thus, with every pulsation of electricity transmitted, an air-valve is opened, and a consequent vibration of the escapement and advance of the wheel and type is made, corresponding with the revolution of the cylinder and break-wheel of the composing machine.

Placed on a pulley, at T, is a coil of paper, on which the messages are printed; when the machine is in operation this paper strip is drawn off, and passes by a toothed cylinder between the coloring-band, S, which revolves about this cylinder and the escapement or type wheel. Whenever the type-wheel makes a sufficient pause (not less than one tenth of a second), by depressing a key of the key-board an eccentric wheel at G, through a connecting-rod, draws the toothed cylinder along with the paper and coloring-band against the type of the wheel, and so impresses a letter on the paper.

242. If any desired letter on the type-wheel is placed in a

certain position, and a corresponding key of the composing machine is depressed, by raising that key and again depressing it, the circuit-wheel at one station and the type-wheel at the other station all make a single revolution, which brings the letter around to its former position. Any other letter is brought to this position by pressing down its key, the circuit being broken and closed as many times as there are letters from the last one taken to the letter desired.

Within the dome, at P, revolves the letter-wheel. This has painted on its circumference the letters to correspond with those of the keys below. In transmitting a message, each letter printed at the remote station is shown at a small opening in the front of this dome, so that, in case from any cause those of the keys do not correspond with those of the type-wheel, the disagreement is at once shown, and the type-wheel set to correspond.

243. In transmitting a message, the machine is set in motion, a signal given, and then, with the communication before him, the operator commences to play, like a pianist, on his keyboard, touching in rapid succession those keys marked with the consecutive letters of the message to be transmitted. On hearing the signal, the operator at the receiving-station sends back the signal, "ready," and then the communication is transmitted.

The function of the electric current in this machine, together with the condensed air, is to preserve equal time in the printing and composing machines, that the letters in one may correspond with the other. The electric pulsations determine the number of spaces or letters which the type-wheel is permitted to advance; they must be at least twenty-five per second *to* prevent the printing machine from acting. The intervals of time the electric current is allowed to flow unbroken are equal, and the number of magnetic pulsations necessary tc

What is said of the Fire-Alarm or Municipal Telegraph?

indicate a different succession of letters are exceedingly unequal; from A to B will require one twenty-eighth of a revolution of the type-wheel, and one magnetic pulsation; from A to A an entire revolution of the type-wheel and twenty-eight magnetic pulsations.

The battery for operating this Telegraph is the same with that for Morse's Telegraph.

244. *The Fire-Alarm Telegraph.*—This may be reckoned among the most ingenious and useful applications of Electro-Magnetism yet devised, and is due to the genius and skill of Dr. W. F. Channing, of Boston, where it was first applied in 1851.

The design of this Telegraph is to communicate simultaneously to various quarters of the city, or town, an alarm in case of fire, riot, or other catastrophe, announcing, at the same time, the section in which these dangers exist. In this alarm-arrangement there are three prominent parts or divisions. First, the *Central Station*, where the batteries and various instruments of communication are placed; second, the *Signal Circuit* of wires for receiving and transmitting signals between the central station and various points; and, third, the *Alarm Circuit*, by which an impulse is sent out from the Central Station to the machinery by which the alarm-bells are struck.

In Boston the city is divided into seven Fire Districts. When a fire breaks out in one of these, the watchman or other authorized person in that district goes immediately to the Signal Box, which he opens with a key, and gives six turns of a small crank; this communicates the danger and the point whence it proceeds to the Central Station, from which an alarm is at once struck on the various alarm-bells, corresponding with that of the district; thus the firemen or police are directed to the proper quarter. Should the fire or other cause of alarm be soon subdued, a signal, "all out," may be sent to the Cen-

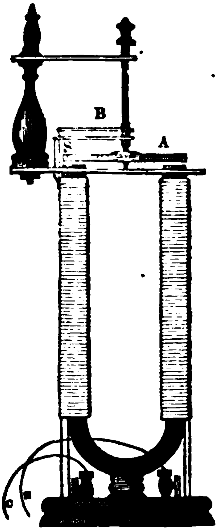
The design of this Telegraph? The three prominent divisions? State the manner in which an alarm is given in case of fire or other danger.

tral Station, and the intelligence be immediately given through the same alarm-bells.

The wires communicating with the signal stations and the alarm-bells pass on insulating supports above the buildings, free from danger of injury. The striking arrangement is similar to that of a common town-clock, and is set in motion by an electro-magnet worked by the battery at the Central Station, and a second local battery.

The utility of the Municipal Alarm-Telegraph has been fully tested in most of the large cities both in this country and Europe, and found to equal the most sanguine expectations of its projectors. A full and complete description of this Telegraph, from the pen of Dr. Channing, will be found in the American Journal of Science, vol. XIII., Second Series.

Fig. 218.



245. For illustrating the manner in which motion and power may be produced by the electro-magnetic force, a variety of ingenious machines have been devised; a few of these we will describe.*

The *Revolving Armature*, Fig. 218, consists of a bar armature, A, arranged to revolve in a horizontal

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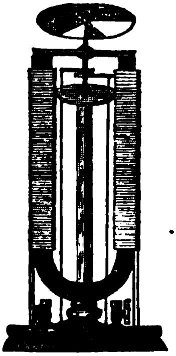
* Among the manufacturers of machines for illustrating the properties of Magnetism, Galvanism and Electro-Magnetism, may be mentioned Mr. Daniel Davis, junr., of Boston, who has earned an enviable reputation in these departments of philosophical manufacturing. Mr. Davis has recently retired, and been succeeded by Messrs. Palmer and Hall, who continue the business successfully at their rooms, 158 Washington-street, and well merit the patronage of the scientific public.

Describe the Revolving Armature. Explain its operation, as given in the experiment.

plane just above the poles of an electro-magnet, fixed in a vertical position, as seen in the figure. To the axis of motion of this armature, at B, is affixed a break-piece. This is formed by filing away two opposite sides of the vertical shaft, so that the small silver springs at S shall bear upon it during only a portion of its revolution. One of these springs connects with one of the screw-cups, and the other, through the wire which surrounds the arms of the magnet, with the other.

Experiment.— Upon connecting the poles, C Z, of the battery with the screw-cups, an electric current, flowing through the wire, strongly charges the magnet. If the armature be now turned so as to stand a little inclined from a right angle with the plane of the magnet, it will be attracted towards the poles of this; but, on reaching these, the springs will cease to touch the shaft, and the current will thus be broken. The attraction of the magnet being now destroyed, the momentum of the armature will carry it forward little more than quarter of a circle, when the springs will again touch, and the electric current again pass, causing the magnet once more to act, and drive forward the armature. Thus, by a systematic series of breaks and connections, great speed and considerable momentum may be acquired.

Fig. 219.



246. Fig. 219 is a modification of the last instrument, designed for showing the effect of rapid motion in blending colors. In this the axial shaft revolves on a support between the poles of the magnet, having the break-piece beneath the armature. Upon the end of the shaft above is fixed a thin pasteboard disc, upon which are painted the seven primary colors.

Experiment. — Connect with the battery, and turn the armature away from the plane of the magnet, as in the last experiment, when it will commence a revolution

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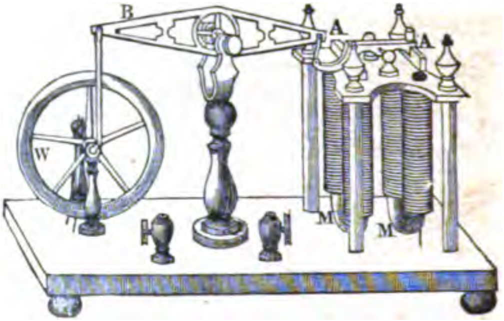
What does Fig. 219 show?

carrying with it the disc so rapidly as to cause the seven colors to appear blended in one, viz., a brownish white.

247. The *Reciprocating Armature Engine*, Fig. 220, is an interesting contrivance for showing the reciprocating and rotary motion which may be imparted by the electro-magnetic influence. Two electro-magnets, M M, are firmly secured in a vertical position, having their four poles appearing just above the small wooden table. Two armatures, A A, connected by a brass bar, move on a horizontal axis in such a manner that while one is approaching the poles of the magnet over which it is placed, the other is receding from those of the other magnet. The brass bar is connected with one extremity of the horizontal beam, B, which communicates motion by means of a crank to the fly-wheel, W.* Upon the axis of this wheel is a break-piece,† which regulates the magnetism of the magnets.

Fig. 220.



Experiment. — Connect the screw-cups with the battery, and the electric current will traverse the wires of each magnet, causing them to become alternately charged, and attract the

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* By attachments to the beam, or to the shaft of the fly-wheel, motion may be given to a miniature saw-mill, or other amusing contrivances.

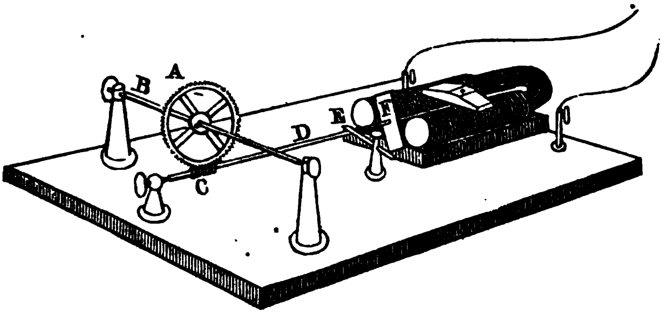
† Davis' Manual.

Describe the Reciprocating Armature Engine, Fig. 220. How does the passage of the galvanic current give motion to this?

armatures, thus communicating a rapid reciprocating motion to the beam, and consequently a rotary one to the fly-wheel.

248. *Davenport's Electro-Engine.*—Fig. 221 is a form

Fig. 221.



of engine for multiplying the power produced by the revolution of the armature before the poles of an electro-magnet. In this, the communication between the two poles of the battery is through the wire of the magnet, G G, up the pillar for the break-piece, and along this to the shaft D, at E, along which it passes to a support between the arms of the magnet, where it flows down this support, and off upon the other battery-wire. The flow of the current is broken by the spring at E, just as the armature, F, is moving by the poles of the magnet, similar to the machines previously described.

A perpetual screw upon the shaft at C plays into the wheel, A, causing this to revolve comparatively slow, but with considerable power. By a drum fixed upon the shaft, B, motion is communicated to other machines. This, in principle, is the method by which mechanical power is obtained by the electro-magnetic force.*

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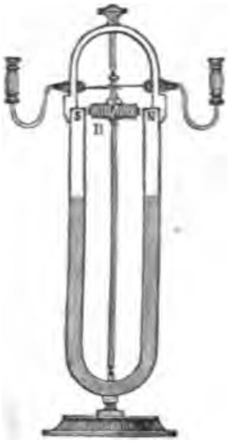
* It was formerly thought that this force might be indefinitely increased, and so serve as an efficient motive-power for propelling machinery. It is found, however, that the electro-magnetic power does not increase in a corresponding ratio with the size of the machine and expense of the materials employed. No improvements will probably realize for this, motive-force once anticipated.

249. The *Revolving Electro-Magnet*, Fig. 222, affords an instance of rapid motion produced by the reciprocal action of a common steel magnet and an electro-magnet. A common U-magnet, placed in a vertical position, has a small, straight bar electro-magnet, B, fixed to a vertical shaft so as to revolve between its poles.* The ends of the wire of this electro-magnet are soldered to two segments on opposite sides of the shaft, insulated from each other and the shaft. Two small silver springs, connecting with the screw-cups at the sides, press alternately on these segments (see Fig. 205), ceasing their bearings while the electro-magnet is passing by the plane of the U-magnet, thus causing the polarity of the former at this point to be destroyed, and to be renewed again in a reverse direction, when the electro-magnet shall have moved along so as to bring the springs again in contact with the segments.

Fig. 222.



By this means, the direction of the current through the wire, and, of course, the polarity of the bar, B, are twice changed during each revolution. Thus the position of the two magnets to each other is such, that, during the first quarter of the revolution, a mutual repulsion of like poles, and, during the second quarter, a mutual attraction of unlike poles, takes place, causing the bar and shaft to revolve by the action of four conspiring forces.

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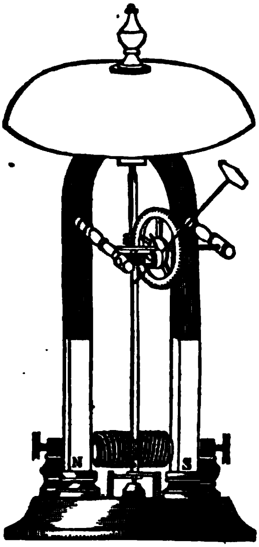
* The bearings on which these electro-magnets revolve are delicate, and the instrument, without proper care, may become easily injured and rendered inoperative.

What does the Revolving Electro-Magnet illustrate? Describe the parts of this. State the direction of the flow of the galvanic current through the horizontal bar armature during its revolution. How does this change of the flow of the current act to give motion to the armature?

Experiment.— Connect the screw-cups of the Revolving Electro-Magnet with a Sulphate of Copper Battery, and turn the bar, B, slightly from the plane of the U-magnet, when an electric current will pass through the wire and springs, between the two poles of the battery, causing the bar and shaft to revolve with surprising velocity.*

Fig. 223.



An ingenious modification of this instrument has a bell arrangement attached, as shown in Fig. 223, whereby the rate of revolution of the bar and shaft may be accurately measured

250. *Wires conducting electric currents, if free to move, attract each other when the currents are moving in the same, and repel each other when moving in the opposite direction.*—We have seen (§ 151) that bodies charged alike with electricity *at rest*, repel, while, charged unlike, they attract each other. Such is not the case with electricity *in motion*, since currents of the *same* electricity, moving in the same direction, attract each other.

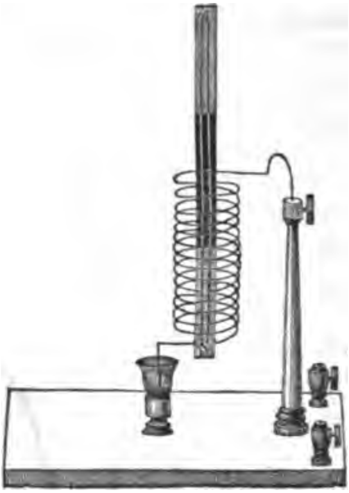
* These electro-magnetic machines for showing motion, merely, should be worked with a battery of low intensity. The Sulphate of Copper Battery is a convenient form. An instance, a few years since, came to the knowledge of the author, where an operator, ignorant of the operations of the galvanic battery, melted down the springs of the pole-changers of several valuable machines, by connecting with a large trough battery when in operation.

Care should be taken to have the springs of this pole-changer press upon the segments with just as much force as is necessary to make and cease their bearings at the proper points. By a proper adjustment of these springs, the bar and shaft may be made instantly to reverse their revolution by simply changing the polar wires from one cup to the other of the battery.

What is said of wires conducting electric currents, and free to move?

The *Contracting Helix*, Fig. 224, will serve to illustrate the attractive power of electric currents, moving in the same direction. A wire loosely coiled is supported in a vertical position at its upper extremity, on the top of a brass pillar which connects with one of the screw-cups, while its lower end just dips in a cup of mercury, which connects with the other screw-cup.

Fig. 224.



Experiment. — Connect the poles of the battery with the screw-cups, and the electric current, traversing each coil of the wire in the same direction, will cause these to be drawn together, and the helix to become thus shortened; this will lift the lower end from the mercury, and interrupt the current, when the helix, by its elastic force, will be again lengthened, and enter the mercury; this will allow the current to pass once more, and contraction will again take place, and thus a rapid succession of vibrations will be kept up so long as the current from the battery is allowed to pass. As the extremity of the wire is lifted from the mercury at each contraction a brilliant spark may be seen accompanied by a slight report. One end of a bar magnet passed down into the helix, as seen in the cut, will render the vibrations much more rapid and energetic.*

251. *Whenever an electric current flows through a wire, it excites another current in an opposite direction, in a*

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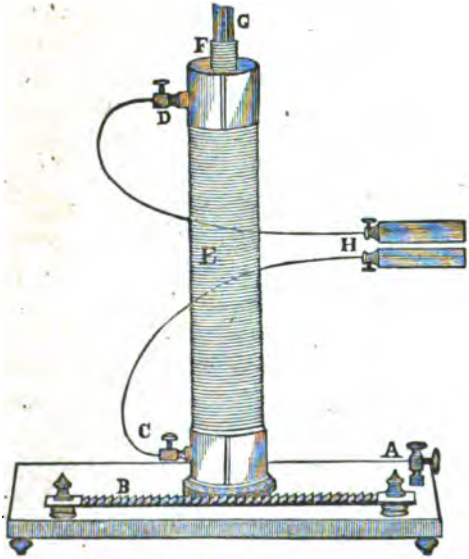
* See that the wire does not enter the mercury so far as not to be lifted entirely out of it by the contraction.

When a current of electricity traverses the wire of the Contracting Helix, Fig. 224, why are the circles drawn together, and the perpendicular length of the coil shortened? Give the proposition section 251.

second wire held near to and parallel with it; and, on suddenly interrupting the first current, the second or induced one instantly reäppears in an opposite direction to the course it first followed.— This proposition may be illustrated by the arrangement shown in Fig. 225, known as the *Separable Helices.* This is composed of two helices of insulated wire, fitting one within the other, but entirely separate. The inner one, F, formed of coarse copper wire, is fixed in a vertical position on the base-board; one of its ends connecting with the screw-cup, A, and the other with the rasp, B. The exterior helix, E, is composed of a great extent of fine insulated wire, which may be lifted off from the inner helix when desired. Its ends are enclosed in two brass caps, to which are soldered the extremities of the wire. Attached to these caps are the screw-cups, C and D. A bundle of annealed iron wires, G, is placed within the inner helix, and may be removed at pleasure.

Fig. 225.



Describe the construction of the Separable Helices, Fig. 225. Give the experiment with the Separable Helices.

Experiment. — Attach one pole of a battery to the screw-cup, A, and draw the end of the other over the rasp; bright sparks will be seen at each interruption of the current, and if the metallic handles, H, connecting with the outer helix, be grasped by the hands, shocks will be felt in the wrists and arms, as the wire is passed along the rasp.

252. Thus the *primary* or battery current, which flows through the inner helix, induces a *secondary* current in the outer. This secondary current is momentary in its action, and appears only at the opening and closing of the primary circuit, and is more intense in its effects than this latter. The current excited in the outer helix by the *closing* of the primary circuit, is called the *initial* secondary, and that upon the *opening* of this, the *terminal* secondary. These two currents flow in opposite directions, and always contrary to the course of the primary current, as may be shown by the deflection of the needles of two delicate galvanometers, placed in the circuit of each current.

253. The action of the terminal secondary is much more intense than that of the initial. This may be shown by connecting the wire of the inner helix, Fig. 225, with a cup of mercury instead of the rasp. Upon *closing* the primary circuit, by plunging the end of the wire leading to the battery in the mercury, the shock produced by the initial secondary current, thus formed, will be found much less severe than that from *opening* the circuit when the wire is raised from the mercury.

Experiment.—While the primary current is flowing through the inner helix, and the handles are grasped as in the last experiment, slowly introduce into the vertical opening the bundle of wires, G. The intensity of the shocks will be greatly increased, and, when the wires are fairly entered, will often be too severe for endurance.

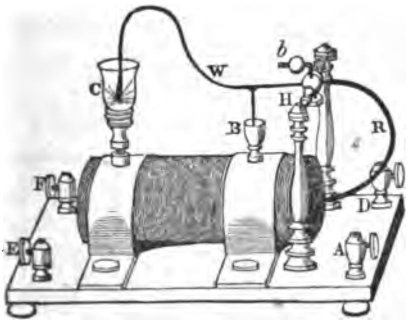
Explain the flow of the primary and secondary currents in this experiment. How do the terminal secondary and initial currents compare in their effects? How may this be shown? What is the effect of introducing a bundle of wires into the inner helix while the galvanic current is flowing through it?

These wires become powerfully magnetic, and reäct on the electricities of the two coils, so as to increase the energy of their action; the withdrawing of even a single wire from the bundle perceptibly affecting the power of the two currents. If, instead of the wires, a solid bar of soft iron be introduced into the opening, a similar but less powerful reäction will be produced.

254. The shocking or decomposing effects of the secondary current are much greater when the interruptions of the primary current are frequent. To ensure a rapid succession of breaks and contacts various plans have been proposed, as the rasp, already mentioned, ratchet, and cog-wheels moved by clock-work, etc. None have, however, effected this with greater convenience and efficiency than that where an armature moved by a temporary magnet is employed.

255. The *Compound Magnet and Electrotome*, Fig. 226, is one of the most amusing and efficient instruments yet devised for showing the action of these secondary currents. Two helices inclosing a bundle of wires, similar to the arrangement in Fig. 225, are placed in a horizontal position, and held firmly to the base-board by two brass bands. The screw-cups, A D, receive the battery connections. From A leads a wire, connecting with the band which supports the mercury-cup, C, while to D is soldered one end of the inner or primary coil, the other end of which is connected with the band on which is fixed the small mercury-cup,

Fig. 226.



How do frequent interruptions of the primary affect the action of the secondary currents?

B. The bent wire, W, is arranged to vibrate up and down on the horizontal axis, H, while its two points, at B and C, just dip into the mercury of these cups. The curved iron rod, R, attached also to H, is bent, so that its lower extremity shall approach quite near the inclosed bundle of wires. For regulating and giving a proper balance to this vibratory arrangement (which should preponderate slightly towards B and C), a small ball, *b*, is made movable on a wire screw attached to the axis. To E F are soldered the ends of the wire composing the outer helix, to which are attached also metallic handles for receiving shocks.

Experiment.—Connect A D with the battery, and the electric current will traverse the inner coil and the bent wire, W; the bundle of inclosed wires will become instantly magnetic, and attract R; this will lift the points of W, at B and C, out of the mercury, and so break the current. The magnetism of the bundle of wires, by which R was attracted, being thus destroyed, the points will again fall into the mercury, and so the flow of the current be renewed, and R again attracted. Thus, a series of rapid vibrations, interrupting the flow of the primary or battery current, will produce a violent action of the secondary. If shocking-handles attached to E F, as in Fig. 227, be now grasped with moistened hands, the shocks will become quite intolerable, causing them, by an involuntary contraction of the muscles, to clench the handles too firmly to be easily released. As the points leave and enter the mercury in B and C, brilliant sparks will be seen, accompanied by sharp snaps.*

256. *Experiment.*—Place one of the handles, Fig. 226, in a glass basin of water, and let a person grasp the other with one hand, while with the other he attempts to remove from the basin any object, as a coin. A violent shock will be felt the instant

* The wire, W, should be nicely balanced, and the points but just enter the mercury.

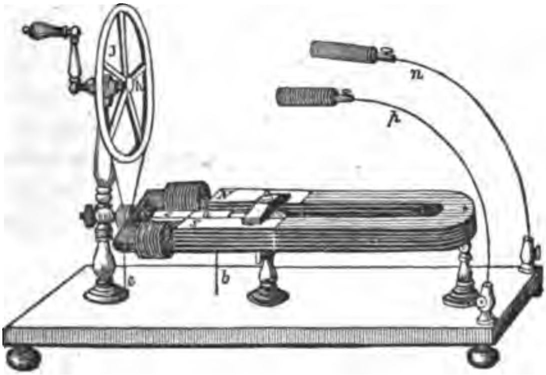
Give the experiment with the Compound Magnet and Electrotome.

the fingers touch the water, causing a sudden withdrawal of the hand. This will be repeated as often as the attempt is made, to the great amusement of the spectators.

By removing the handles, and in their place attaching to the wires small strips of platinum, the various experiments in decomposition of liquid compounds (§ 202) may be performed as with the primary current.

257. *Magneto-Electricity* is the name given to electricity produced by the action of a magnet. As electricity, flowing through a wire surrounding a bar of soft iron, induces magnetism in it, so, on the contrary, a magnetized bar sets in motion a current of electricity in such a wire surrounding it. This may be shown, by introducing one of the poles of a powerful bar magnet within a helix of fine insulated wire, the ends of which are connected with a delicate galvanometer. The flow of an electric current through the wire will be perceptible, by the deflection of the needle, as the magnet enters and leaves the helix, the direction of the current changing with the poles entered.

Fig. 227.



258. The *Magneto-Electric Machine*, Fig. 227, is a con-

What is Magneto-Electricity? How is this form of electricity produced? Describe the Magneto-Electric Machine.

venient arrangement for developing electricity by the reäction of a magnet. A bar armature, G, of soft iron, bent twice at right angles, is made to revolve rapidly before the poles, N S, of a powerful compound magnet, by means of the multiplying wheel, J, which belts off upon a small drum attached to the axis of the armature. The arms of this armature are wound with a continuous insulated wire, the ends of which are soldered to the two segments of a pole-changer attached to the axis as in Fig. 204. Two small springs, pressing alternately on these segments, connect through the wires, *e b*. with the screw-cups at the end of the base-board.

Upon causing the armature, G, to revolve, as its ends come directly before and near to the poles of the magnet, this armature becomes itself strongly magnetic. This sets in motion the natural electricity of its helices, which flows in a certain direction, and is conveyed through the springs and wires, to the screw-cups. As the armature moves on, when at right angles with the plane of the magnet, it loses its previous magnetism, and begins to acquire a new charge of an opposite polarity; this excites in the helices a new current in a reverse direction; this, by means of the pole-changer, is turned in the same direction as the former current, and conveyed to the screw-cups. Thus, the magnetism of the armature is twice changed during each revolution, exciting in the helices two electric currents, flowing in opposite directions.

By attaching to the screw-cups the shocking-handles, p n, and causing the armature to revolve rapidly, shocks similar to those in Experiment, § 255, may be received. The Magneto-Electric Machine has been also successfully employed with the Telegraph, and as a substitute for the Galvanic Battery in Electro-Metallurgy.

259. Few departments of natural science possess, at present, more general interest than those of Galvanism and Electro-Magnetism; being connected, as they are, so extensively, with

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Explain the manner in which electricity is produced by this machine.

wonderful and important phenomena. The researches and practical discoveries of Faraday, Henry, and others, have done much of late to call attention to these sciences, and disclose a fruitful field for investigation, as yet but partially and imperfectly explored.

The applications of galvanic electricity, since it was first discovered, are of the most varied and wonderful character. By it the telegraph operator can write, with his iron pen, a letter, three thousand miles distant. By it the electrotypist coats the most common metals with silver and gold; by it metals are extracted from aqueous solutions and even from the human system. It is employed to plate medallions, busts, jewelry, and even the very type which prints the words we write. It can produce the most intense and brilliant of artificial lights, and, in its blaze, the diamond and the hardest of metals become as wax. As a motive power, galvanic electricity has not yet succeeded to that extent which promises its introduction to any considerable degree in the propelling of machinery. That it may not yet be successfully applied for such purposes, we dare not in this age of inventions positively say.

In the previous chapters we have attempted only a brief outline of these subjects, and for more extended information the student is referred to Smees' Electro-Metallurgy, and Davis' Manual of Magnetism, a thorough and practical treatise, well deserving a careful perusal.

What is said of the interest now attached to Galvanism and Electro-Magnetism? Why this interest? What is said of the applications of galvanic electricity since its discovery? Give some illustrations. What is said of this as a motive power?

LIGHT.

260. Light is that mysterious physical agent by which the eye perceives external objects. Of its essence we know nothing, and can only judge of it by the effects which it produces.

Two prevailing opinions exist in regard to the nature of light; one, known as the *Newtonian Theory*, regards it as composed of infinitely minute atoms of matter thrown off from luminous bodies, and impinging on the organs of vision to produce sight, the same as odoriferous effluvia on the nasal organs to produce the sense of smell; the other, called the *Undulatory theory*, supposes light simply as the result of undulations or waves excited by luminous bodies in an exceedingly subtile medium called ether, and which traversing this medium produces on the eye effects analogous to the vibrations of air on the ear in causing sound.*

Light moves with a velocity of about 192,000 miles per second; thus requiring only eight minutes and thirteen seconds to pass from the sun to the earth, a distance of ninety-five millions of miles. Some idea of its surprising velocity may be gained by comparing its rate of motion with the greatest speed yet acquired by the locomotive engine (about one mile per minute). To traverse the distance passed over by light from the sun in eight minutes and thirteen seconds, such a body would require nearly one hundred and eighty years.

261. *Self-luminous Bodies or Luminaries.* — Such are

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* As the limits of this work do not allow of considering these theories, the student is referred to Muller's Physics, sect. v. chap. v.; Bird's Natural Philosophy, chap. xxi., and Brewster's Optics, in Lardner's Cyclopedia.

What is light? What do we know of the nature or essence of light? How many theories exist in regard to the nature of light? State the Newtonian theory. The Undulatory theory. At what velocity does light move? How does the speed of light compare with the fastest locomotive? What are self-luminous bodies?

the original sources from whence all light proceeds. Of these the sun, a lighted candle, and phosphorescent bodies, are examples. Such dispense their light in every direction from myriads of luminous points extending over their surfaces, and thus render visible the various objects on which their rays may fall. Bodies not self-luminous are either opaque, transparent, or translucent.

Opaque bodies are such as wholly intercept the passage of light, and are visible only by the presence of self-luminous bodies. Thus, the moon, the planets, and most objects on the earth, are opaque, and, when placed between the eye and a luminous source, so intercept the light from this as to render it invisible.

262. *Transparent bodies* are those which afford a passage for light sufficiently free to allow of our seeing distinctly the forms of objects placed behind them. These differ in the degrees of their transparency. Some, like thin plate-glass and portions of air, which are wholly invisible, are said to be *perfectly transparent;* others, as the better qualities of window-glass and most crystals, which are themselves visible, yet allow objects to be distinctly seen through them, are called *transparent*, merely; while those bodies through which objects are indistinctly seen, as ground-glass, clouds of smoke, etc., are said to be *semi-transparent.*

Translucent bodies are those which allow a mere glimmering of light to pass them, insufficient to show either the color or form of an object. Such, for example, are plates of horn and colored shell.

A *ray of light* is simply the line which light makes in its progress through space. A *pencil of light* is a collection of rays diverging from, or converging to a point. When a col-

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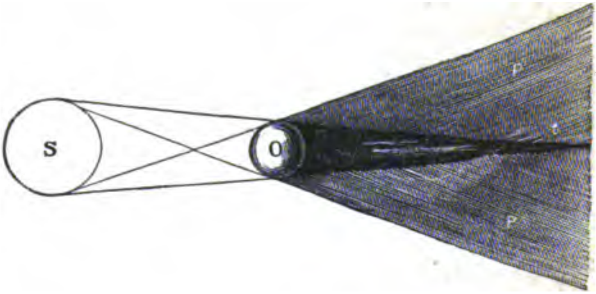
Give examples. How do these dispense their light? What are opaque bodies? Give examples. What are transparent bodies? Examples? What are translucent bodies? Examples? Define a ray of light. A pencil of light

lection of rays proceed from a luminous body in parallel lines it is termed a *beam* of light.

263. *Light proceeding from a luminous point moves in straight lines so long as the medium which it traverses is uniform.* — As a consequence of this, if an opaque body be presented to the light from a luminous source, it will intercept those rays thrown upon it, and cast *a shadow* on the side opposite the light. The form of the shadow depends on the shape and relative size of the luminous and opaque bodies. Thus, if the light proceed from a point or luminary smaller than the opaque body, the shadow will diverge as it recedes from this opaque body; but if the luminary be larger than the opaque body, the shadow will converge, and terminate in a point at a greater or less distance from the body.

264. *Shadow and Penumbra.* — If the luminous body considerably exceed in size the opaque, there will be formed, besides the true converging shadow, a half shadow, or penumbra, on each side of this, as seen in Fig. 228. Here S is the luminary, and O a smaller opaque body, behind which is formed the true shadow terminating at *t*. From the space occupied by this true shadow the whole of the light from S is excluded, but

Fig. 228.



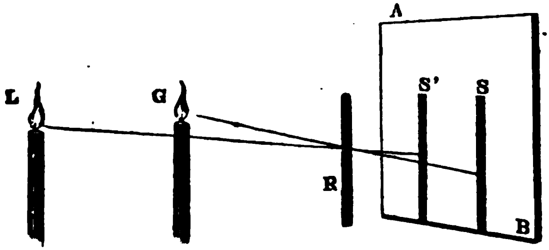
A beam of light. How does light from a luminous body proceed? What is said of the form of the shadow? What will be formed when the luminary exceeds in diameter the opaque body? How is the penumbra produced, and how does it differ from the true shadow, as shown by Fig. 228?

on each side of this is a space, P P, which receives a portion of the rays from S, and is called the *penumbra*. Near O the outline of the two shadows is quite clearly defined, but further from this, towards *t*, they become less distinctly marked, until near *t*, where the true shadow terminates, they become well-nigh blended. Beyond the point at *t* the true shadow ceases, and the penumbra goes on, growing wider and more faint, until it disappears in the distance.

265. *The intensity of light diminishes as the square of the distance from the luminary increases.* — Thus, light observes the same laws as gravitation, sound, and other radiant forces, varying in intensity with the extent of surface over which a given portion spreads itself. Accordingly, if a given surface, at the distance of one foot from a candle, receive a certain number of rays of light, the same surface, removed to a distance of two or three feet, would receive four or nine times less number of rays. In other words, the intensity of the illumination at a distance of one foot from a single candle would be the same as that from four or nine candles at a distance of two or three feet, these numbers being the squares of two or three, the supposed distances from the candle.

266. The *Photometer*,* an instrument for comparing the intensities of light from different sources, has its action based on the above proposition. These are of different forms. Fig. 229

Fig. 229.



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* *Photos*, light, and *metron*, a measure.

How does the intensity of light from a luminary diminish? Give an illustration of this proposition in the case of a candle. What is the Photometer?

shows, however, the most simple arrangement of the Photometer. A B is a vertical white screen, near to and directly in front of which is placed a perpendicular rod, R. From this rod two shadows, S, S′, are cast on the screen by the candles, G, L, these shadows just touching without overlaying each other, and each being illumined by the light forming the other shadow. If, now, a perceptible difference exist in the two shadows, and S, formed by G, be the darker, remove the candle, G, further from the screen, keeping the shadows in the same position, until both be equally illumined. By comparing the squares of the distances of the two candles from the screen, when their positions are thus changed, the comparative intensities of the lights from these may be ascertained. Thus, if L be now 2 and G 3 feet from the screen, the intensities of their lights will be to each other as 4 to 9.

267. *The intensity of the sun's light exceeds that from any other luminary with which we are acquainted.* — The illuminating power of a light depends not only on its absolute intensity, but also on the extent of the luminous surface from which it radiates. Thus, the vast area of the sun, radiating to us light from a hemisphere of nearly a million and a half square miles, causes the intensity of his illumination to exceed by far the light from the brightest artificial lights that can be formed.* Even the intense brilliancy from charcoal points, when acted on by the galvanic current, § 270, is found inferior to that from solar light; and, according to Dr. Wollaston, it would require more than 5,500 wax candles, at a distance of one foot, to equal the intensity of the sun's light.

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* The light from the moon is found to be 801,072 times less intense than that from the sun. Few persons are able from common observation to judge with any degree of accuracy of the comparative intensity of the light from different luminaries.

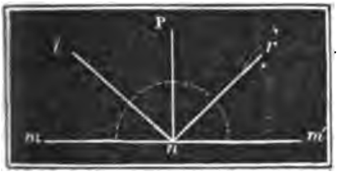
Show from the figure how the degree of light from a luminary may be measured. What is said of the light from the sun? Why is the light from this so intense? How does the sun's light compare with the most intense artificial lights?

REFLECTION OF LIGHT.

268. When light falls on any opaque body, a portion of it is absorbed, and the remainder turned back or *reflected* from the surface of the body. The amount and direction of this reflected light depend on the nature of the surface on which the light falls. If the body have a regular and highly-polished surface, nearly all the light will be reflected in a certain definite order; but if its surface be irregular and unpolished, only a small portion will be thrown back, and that in the most irregular and confused manner. The former is an instance of *regular*, and the latter of *irregular* reflection. It is by the irregular reflection of light that most objects in nature become visible; and since this is thrown off, in all directions, from the irregular surfaces of material bodies, it renders luminous and visible those not reached by the direct light from luminaries.*

269. *When light falls on a plane and polished surface, as a mirror, it follows the same laws of reflection as solids* (§ 21), *its angles of incidence and reflection being equal.*— Let *i n*, Fig. 230, be the direction of an incident ray of light, falling on the mirror, *m m*, and *n r* its course when reflected from this. Upon drawing a perpendicular, P *n*, to the plane at the point of reflection, it will be found that the angle of incidence, *i n* P, is precisely equal to that of reflection, *r n* P.

Fig. 230.



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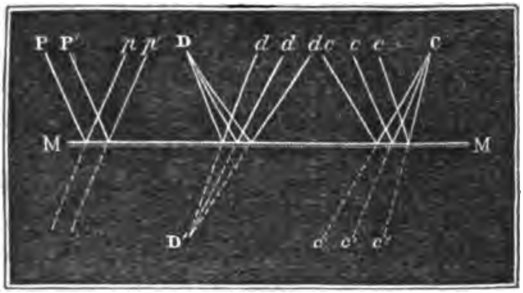
* It is the reflection and refraction of the sun's light by the atmosphere and the bodies which are suspended in it that produces the agreeable twilight, and so causes the transitions from day to night, and from night to day, to be gradual.

What is said of light which falls on an opaque body? What is an instance of regular reflection of light? Of irregular reflection? How do most objects in nature become visible? What laws does light reflected from a plane surface follow? Explain Fig. 230.

This same law holds good in regard to every form of surface, curves as well as planes, since the former may be supposed formed from an infinite number of minute planes.

270. *Rays of light falling on a plane mirror are reflected from it at the same angle as they approached it, and appear to proceed from points just as far behind the mirror as those from which they issued were before it.*— This is in accordance with the proposition previously stated, and may be illustrated by Fig. 231. Let M M be a plane and polished mirror, on which are incident the parallel rays, P P′, the divergent, D, and the convergent rays, *c c c*. The first are reflected back to *p p′* parallel; the second, diverging from D, are thrown back at the same angle to *d d d*, and appear as if diverging from D′, a point behind the mirror; the third, converging from *c c c*, are reflected, converging to the point C, as though coming from *c′ c′ c′*, behind the mirror.*

Fig. 231.



271. *If the object form an angle with the mirror, it will form double that angle with its image.*— Let A B be an

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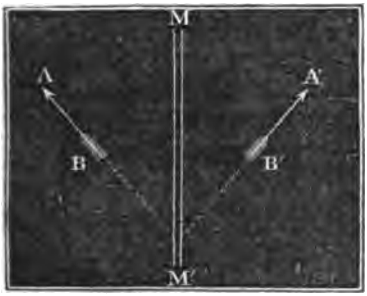
* Mirrors are reflectors formed by coating the backs of polished glass plates with a brilliant amalgam of tin and quicksilver, while speculums are reflectors made from highly-polished metals. The latter afford the more perfect reflectors, being used for telescopes and other optical instruments.

State Proposition 270. Explain Fig. 231. If an object form an angle with a plane mirror at what angle will an image appear?

object inclined to the mirror, M M′, Fig. 232, and forming with it the angle B M′ M; then will the image A′ B′ be inclined to the mirror at the same angle, B′ M′ M; the sum of these angles, B M′ B′, will be, therefore, the angle which the image makes with the object, and double the angle which either makes with the mirror. Accordingly, the image from an object in a horizontal position, formed by a mirror inclined at an angle of 45°, will appear erect. If the mirror be horizontal, and the object in a *vertical* position, the image from such object will be *inverted.* Hence it is that the images of trees and other objects bordering on a smooth sheet of water appear inverted.

Fig. 232.



If an object be placed between two plane parallel mirrors, a series of objects will be produced, lying on a straight line drawn through the object perpendicular to the reflector. This is seen in rooms having mirrors placed parallel on opposite sides of the room, with a lustre or other object suspended between them. An interminable range of lustres will appear in each mirror, which lose themselves in the distance by reason of their faintness. This increased faintness is caused by the repeated reflections, which diminish in each successive reflection the amount of light, causing the objects to appear to recede in the distance.*

272. *If two plane mirrors be inclined towards each other at any angle, images from an object placed between them will be multiplied according to the degree of the angle.*—

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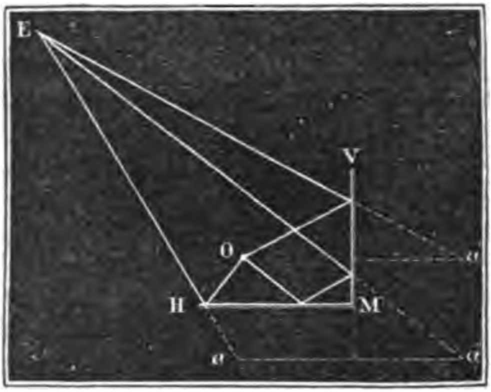
* Lardner.

Why do trees and other objects bordering on a smooth sheet of water appear inverted? State the proposition, section 272, in regard to two mirrors inclined to each other at any angle.

This may be shown by the arrangement seen in Fig. 233. Let V M, and H M, be two mirrors, forming with each

Fig. 233.



other an angle of 90°, and O an object placed between. The eye at E will see not only the object at O, but also its images at *a* and *a′*, caused by a reflection of the rays proceeding directly from O. Another ray from O falling on H M, will be reflected to V M, from which it will undergo a second reflection, and meet the eye, causing a third image at *a″*. Thus, with the mirror inclined as in the figure, the eye at E will see, besides the object itself, three images from as many different points. If the mirrors be inclined to each other at an angle of 45°, *seven* images of O will be seen, which, with O, will be arranged at eight angles of a regular octagon, of which the point, M, where the mirrors meet, will be the centre. By giving a still greater inclination to the mirrors, the number of images will be proportionably increased; and, if the angle of inclination be an aliquot part of 360°, the images will be arranged on the sides of a regular polygon.

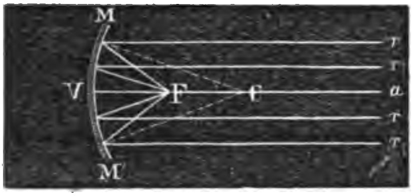
If the mirrors be placed so as to form with each other an angle of 90°, how many images of the object will appear? If inclined at 45°, how many images? When the mirrors are inclined at an angle which is an aliquot part of 360°, how will the images be arranged? What optical toy acts on this principle?

Upon this principle rests the construction of the *kaleidoscope*, which consists simply of two pieces of common looking-glass, arranged in a tube at a certain angle, between which are loosely placed semi-transparent bodies, of various colors, to be reflected.

273. *Curved Reflectors.*—If a segment of a hollow sphere, whose inside surface is brightly polished, be cut off by a plane, this segment will form a *concave mirror.* Such a mirror tends to collect the rays of light thrown upon it, and bring them together. The point where the rays reflected from a concave mirror meet is called the *focus* (fire-place) of the mirror.

Parallel rays of light falling on a concave mirror, near the axis, are reflected to a focus at a point half way between the vertex and centre of the sphere described by the mirror.—Let r a r, Fig. 234, be parallel rays proceeding from a distant luminary, as the sun, and falling on the spherical concave mirror, M M′; these rays will be converged to a focus at F, equidistant from the vertex, V, and the centre, C, of the sphere described by the mirror.

Fig. 234.



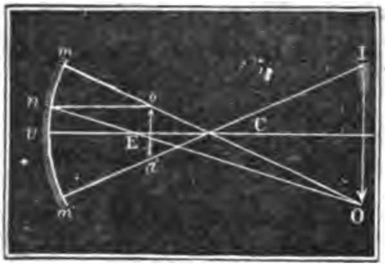
This focus is called the principal focus; when the arc or aperture of the mirror exceeds about five or six degrees on each side of its axis, the parallel rays falling on the parts without this limit are converged to a point nearer the mirror than the principal focus, producing an *aberration* of the reflected light. To prevent this, and converge to a single focus *all* the rays that fall on the mirror, those with *parabolic* curves are constructed. Such are known as burning mirrors.

What is a concave mirror? What is said of rays of light falling on a concave mirror? How will parallel rays of light falling on a concave mirror, near its axis, be reflected? What is the point where these parallel rays meet after reflection called? Why are burning mirrors made with a parabolic surface?

Diverging rays, incident on spherical concave mirrors, will be converged to a point further from the mirror than the focus of parallel rays, or the principal focus.

274. *Images formed by concave mirrors vary in size and position according to the distance of the object from the mirror.*—Let *o i*, Fig. 235, be an object situated between the centre of curvature, C, of the mirror, and the principal focus, E. The rays, *o m*, *o n*, from the point *o*, will, according to principles already illustrated, be reflected, and intersect at O, to form an image of *o* behind C. The rays from *i* will in like manner form an image of it at I, and so every intermediate point between *o i*, will have its corresponding image between O I.

Fig. 235.



Thus, by means of a concave mirror, *m m'*, we may form on a screen, placed beyond the centre of curvature, an inverted and enlarged image of the object, *o i*, lying between it and the principal focus. If, on the other hand, I O be the object beyond the centre of curvature, the rays from it meeting the mirror will form at *o i*, an inverted and smaller image. By placing the object nearer the mirror, between it and the principal focus, an image *erect* and greatly magnified will appear behind the mirror.

275. The above explanation of the properties of concave mirrors enables us to understand the manner in which many optical phenomena, which have so astonished the ignorant of

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How will diverging rays incident on a concave mirror be reflected? What is said of images formed by concave mirrors? Illustrate this by Fig. 235. If I O be the object, where and what kind of image will be formed? What wonderful phenomena does this explanation of the properties of the concave mirror enable us to understand?

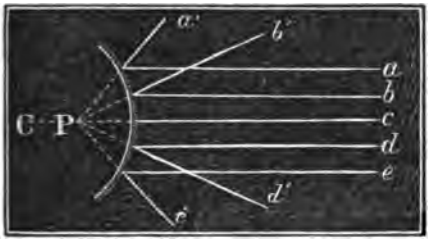
past ages, are produced. Thus a concave mirror concealed behind a partition may be made to throw a magnified image of an object, also concealed, through an open door, into an adjoining room, upon a semi-transparent screen or cloud of vapor, causing it to appear suspended in the air before the eyes of the spectators. In this way, hideous images of skulls, daggers, etc., may be formed in the air without any visible cause.

Concave mirrors are used as reflectors for light-houses, to render the light more intense in particular directions. These are also employed as *burning mirrors.* It was by means of an arrangement of reflectors, forming one huge concave mirror, that Archimedes was enabled to fire the Roman fleet under Marcellus, at a considerable distance from the walls of Syracuse.

276. A convex mirror may be formed by polishing the exterior surface of a spherical concave mirror.

Parallel rays of light falling on a convex mirror are made to diverge as if proceeding from a point behind it.— This point is termed the imaginary or virtual focus. Let *a*, *b*, *c*, *d*, *e*, Fig. 236, be parallel rays, incident on a convex mirror, whose centre of curvature is C. These rays are reflected in the directions *a′*, *b′*, *d′*, *e′*, as though proceeding from a point, P, behind the mirror.

Fig. 236.

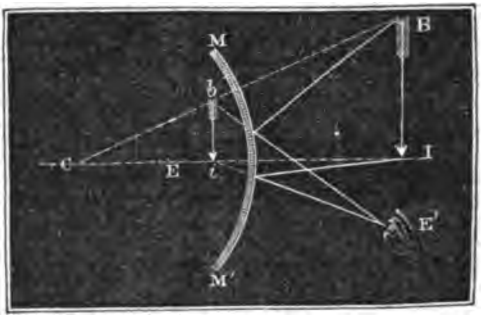


277. *The image formed by a convex mirror is erect and*

Where are concave mirrors used for aiding illumination? What remarkable instance of their use as burning mirrors? How may a convex mirror be formed? State the proposition in regard to parallel rays falling on a convex mirror. Explain this by Fig. 236. How do images formed by convex mirrors appear, as shown in Fig. 237?

much diminished in size.—Let B I, Fig. 237, be an object placed before the convex mirror, M M′, whose virtual focus is at E, and centre of convergency at C. The rays proceeding from B will be reflected from the convex surface to the eye at E′, as though proceeding from a point, *b*, behind the mirror; in like manner those from I will appear to proceed from *i*, and so of all the intermediate points between B and I, thus presenting an image smaller, erect, and much nearer the mirror than the object.

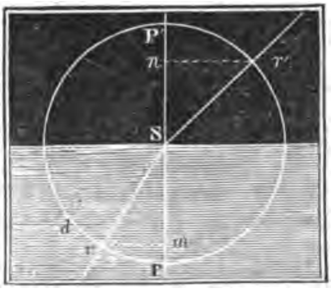
Fig. 237.



REFRACTION OF LIGHT.

278. When light passes obliquely from one medium into another of different density, it suffers a deviation, or change of direction, known as *refraction*. For instance, let a ray of light, proceeding from *r′*, Fig. 238, fall upon the surface of a body of water at S; instead of continuing in a straight line to *d*, it is turned aside at S,

Fig. 238.



What direction does a ray of light take when passing from one medium into another of different density? What is this change in the direction of the ray called? Illustrate this by the passage of a ray of light from air into water, Fig. 238.

and moves in the direction of S *r*, more nearly in a line with P′ P, the perpendicular to the surface of the liquid at the point, S. The angle, P′ S *r′*, which the ray makes with the perpendicular before entering the water, is called the *angle of incidence;* the angle, P S *r*, which it forms with this after entering it, the *angle of refraction;* and *d* S *r*, the *angle of deviation.* Thus, whenever a ray of light passes from a rarer into a denser medium, it is bent *towards* a perpendicular to that medium at the point of entry; but, on the other hand, when it passes from a denser into a rarer, as from water into air, it is turned *from* this perpendicular.

279. *When a ray of light passes from one medium into another of different density, the angles of incidence and refraction sustain to each other a constant ratio, which is expressed by their sines.* — This may be illustrated by Fig. 238, where *r′* S is the incident ray passing from air into water, and S *r* the refracted ray. Suppose a circle to be drawn, intersecting these rays at *r′* and *r;* the line *r′ n*, drawn from the point of intersection, *r′*, at right angles with the radius S P′, will be the *sine* of the incident angle, and *r m*, drawn from the other point of intersection, at right angles with the radius S P, the *sine* of the refracting angle. These sines will vary with their respective angles, and of course with the obliquities of the incident and refracted rays to the perpendicular, P P′.

Upon the passage of a ray of light from air into water, or other medium, these sines will be found to sustain to each other a uniform ratio. Thus, in the case of water, the sine of incidence is $\frac{4}{3}$; that is, *r′ n* is $\frac{4}{3}$ of *r m*, the sine of the refracting angle. In the case of glass, $\frac{3}{2}$; of the diamond, $\frac{5}{2}$, and so on. These fractions denote the refracting power of different media,

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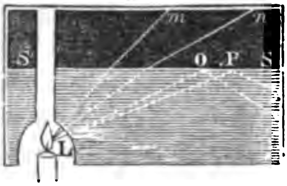
In the figure, which is the angle of incidence? Of refraction? What is the course of light when passing from a rarer into a denser medium? When a ray of light passes from one medium into another, of different density, what is said of its angles of incidence and refraction? Explain this by the figure. What is the refracting angle for water? For glass? For the diamond.

and are hence called their *indices* of refraction. Of the bodies mentioned, the refracting power of the diamond is the greatest, so turning the course of a ray of light incident upon it from a straight line towards the perpendicular, as to make its sine of refraction only $\frac{2}{5}$ of the sine of incidence.*

Inflammable bodies generally possess a much greater refractive power than other substances of equal density; hence it was that Sir Isaac Newton was led to suggest the inflammability of the diamond, long before it was shown by actual experiment to be inflammable.

280. *When the obliquity of an incident ray, passing through a denser medium towards a rarer, is such that the sine of its refracting angle is equal to radius, it ceases to pass out, and is reflected along the surface of the denser medium. If this angle be greater than that at which the sine of the refracting angle equals radius, the ray is reflected back into it again.*—Let a pencil of diverging rays, proceeding from the luminous point, L, Fig. 239, pass with different obliquities towards the surface, S′ S, of a body of water. The rays, L *m*, and L *n*, whose sines of refraction are less than radius, pass out of the water into the rarer medium, while L O, and L P, angles of incidence greater than that at which the sine of the angle of refraction equals radius, are reflected back from the surface of the water, as from a

Fig. 239.



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* An amusing illustration of the bending of rays of light from a direct line, when passing from a denser into a rarer medium, may be given by placing a cent in a bowl, so as to be just hidden from sight to a side observer. Pour water into the bowl; the coin will now become visible, and appear above its true position. From the same cause, ponds and rivers often appear to persons on their banks less deep than they really are. Such optical deceptions occasionally prove fatal to life.

What is said of the refracting power of the diamond? Newton's suggestion in regard to this? State the proposition, section 280, in regard to the reflection of light from the surface of a denser medium, as water. Explain this by Fig. 239.

perfect mirror. The angle at and within which this internal reflection occurs is called the *limiting* angle between refraction and reflection.

This, for water, is 48° 28″; for sulphur, 30°, and for the diamond, 23° 35′. Beyond this limiting angle, the reflection is *total.* Thus, if a wine-glass, nearly filled with water, be held up, so as that the surface may be seen from beneath, it will appear like a sheet of burnished silver.

281. *Mirage*, *Fatà Morgana*, and kindred remarkable atmospheric phenomena, are produced by the refraction and reflection of light, in its passage through, or incidence upon, strata of atmosphere differing in density and refractive power, according to principles already explained. Thus, in certain states of the atmosphere, light passing from an object may proceed at such an obliquity as to be reflected from the upper surface of a denser stratum, and pass by refraction again to the earth. In such case, an object situated behind a hill, or below the horizon, may be brought to view, and appear suspended in the air, in an erect or inverted position. Such phenomena are often seen in great splendor in the Straits of Messina, on the deserts of Africa, and occasionally on the coasts of England and France, in the evenings of hot autumnal days.*

282. *Lenses.*—These are certain forms of transparent bodies used for collecting or dispersing the rays of light which

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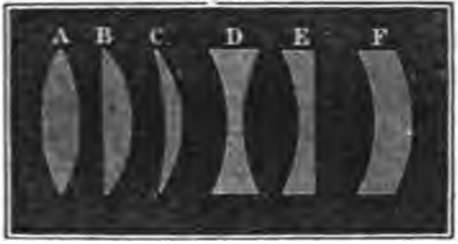
* Captain Scoresby and other voyagers in the polar seas relate seeing many remarkable instances of mirage; as vessels actually below the horizon appearing moving under full sail, and inverted on the sky, etc. Travellers, in passing across the heated sands of Africa, are often deceived by an appearance of water in the distance. So villages far remote, and below the horizon, will at times appear painted on the sky, both in inverted and direct positions. These phenomena may be sometimes imitated by looking at objects over the surface of any heated body, as the boiler of a locomotive, when the objects will appear raised, or perhaps inverted.

What is meant by the limiting angle? What is said of the reflection of light beyond this limiting angle? How may this be illustrated? How is mirage produced? Where is this often seen in great splendor? What are lenses?

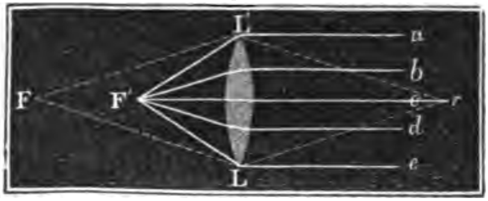
pass through them. Fig. 240 presents sectional views of those commonly employed for optical purposes. The *double-convex* lens, A, has two convex surfaces; the *plane-convex*, B, has one convex, and one plane surface; the *meniscus*, C, has a convex and a concave surface, the curvature of the former exceeding that of the latter, so as to produce a crescent form; the *double-concave*, D, has two concave surfaces; the *plane-concave*, E, a plane and a concave surface; and the *concave-convex*, F, a concave and convex surface, the curvature of the former exceeding that of the latter. The first three, which are thickest at the centre, are called *convergent* lenses, and serve to collect the rays of light passing through them to a focus; while the last three are termed *divergent* lenses, and act to separate these rays.

Fig. 240.



283. *Parallel rays incident on a double-convex lens are converged to a focus at a distance from the lens, varying with the curvature of its sides.*—Let *a*, *b*, *c*, *d*, *e*, Fig. 241, be parallel rays incident on the double-convex lens, L′ L. In passing through the lens, these rays will undergo refraction, and be converged to a point, F′, on the axis, known as the common

Fig. 241.



What kinds of lenses are shown by Fig. 240, and how are they formed? How do the first three lenses differ from the last three? What is said of parallel rays incident on a double-convex lens? Explain this by Fig. 241.

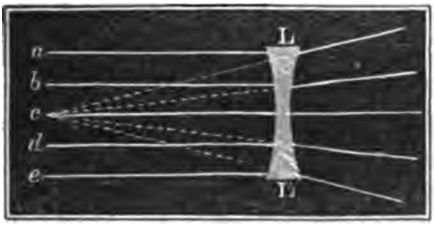
focus. With lenses of the same refracting medium this focus will vary according to the curvature of the sides.

If the rays falling on the lens, L′ L, be *converging*, their focus will be nearer the surface of the lens than F′. If, on the other hand, they be *divergent*, as from the point, *r*, they will have their focus at a point, F, farther from the lens, than that for parallel rays.

284. The rays of light traversing a double-convex lens are not all converged to the same point on the axis. This defect is remedied in a good degree by having the lens of a parabolic form. In the common form of the lens, those rays which pass through it near its edges are converged to a focus nearer the surface of the lens than those which traverse it more nearly parallel with the axis. Such varying of the focal points for rays traversing the lens at different distances from the axis, is termed the *spherical aberration* of the lens. To avoid this aberration in lenses employed for optical purposes, a meniscus (Fig. 240, C) is used with the double-convex lens, by which the rays are made to converge uniformly to a single point.

285. *Rays falling on a double-concave lens are rendered more divergent after than before passing through the lens.* — The parallel rays, *a*, *b*, *c*, *d*, *e*, Fig. 242, falling on the double-concave lens, L L′, after passing through this, are made to diverge as though proceeding from the point, *c*. So convergent rays are rendered less convergent, or even parallel.

Fig. 242.

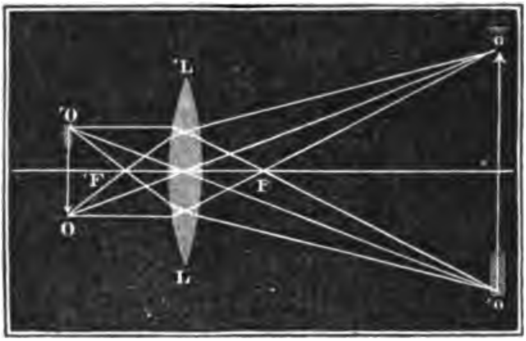


How will be the focus of diverging and converging rays incident on L′ L? What is said of the rays traversing a double-convex lens? How is the aberration of light in such cases remedied in good part? The course of rays of light traversing a double-concave lens? Explain Fig. 242.

Thus, the refraction of light by concave lenses corresponds to its reflection by convex mirrors, both being dispersive in their effects. So, also, the convex lens and concave mirror correspond in their converging power over light.

286. *Images are formed by lenses in the same manner as by mirrors.*—Let O O′, Fig. 243, be an object placed before the lens, L L′, just without its principal focus, F′. The rays proceeding from the point, O, will be converged by the lens, and form an image at *o*; those from O′ will also be converged, and form an image at o′; and so each point between O O′ will have its corresponding image between o o′. Thus, an inverted and magnified image of the object will be formed on a screen at o, o′, owing to the crossing of the rays, and their divergence from the point, F.

Fig. 243.



If the object, O O′, be brought nearer L L′, the image, o o′, will proportionably recede, and become magnified, so that the eye, placed at a favorable point without F, will see an image of the object magnified in proportion to its nearness to the point, F′.

To what does the refraction of light by concave and convex lenses correspond? What is said of images formed by lenses? Explain the manner in which images are formed by a double-convex lens, as shown by Fig. 243. How will the nearness of the object to the lens affect its apparent size?

If, in place of the double-convex, a double-concave lens be employed, the image will appear smaller than the object.

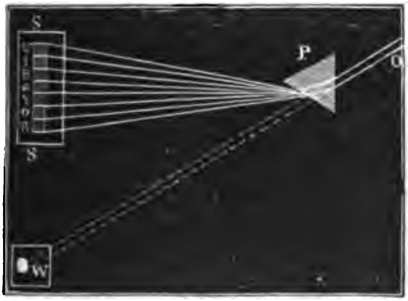
This wonderful property of lenses depends upon the apparent angle under which the object is viewed, the eye seeing the object in the direction in which the rays from the object enter it; so that if these rays be converged to it at a large angle, as in case of the magnifying lens, the object from which they proceed will appear to span the same angle. Hence, the shorter the focal distance of a lens, the greater will be its magnifying power, and *vice versa.*

DECOMPOSITION OF LIGHT.

287. *White solar light is a compound formed by the blending of different colored rays.* — This may be proved by passing a ray of sunlight through some highly refracting medium, whereby the colored rays composing this, and which have different degrees of refrangibility, shall be separated. The instrument commonly employed for this purpose is a triangular *prism* of flint glass, with its three polished sides usually inclined to each other at angles of 60°.

Experiment. — Through a small opening, O, Fig. 244, allow a ray of light to enter a dark room, and fall on a white wall, or screen at W, where will be seen a small round spot of white light. Interpose now a prism, P, and the ray, instead of passing in a direct line to W, will be refracted to S S, forming

Fig. 244.



If a double-concave lens be employed, how will the image appear? Upon what does this wonderful property of lenses depend? What is white solar light? How may this be proved? What is a prism? Explain the manner in which a beam of light may be decomposed, as seen in Fig. 244.

between those points an elongated *spectrum*, composed of bands of seven different colors insensibly passing into each other. These *seven* colors, of which the solar ray is composed, namely, red, orange, yellow, green, blue, indigo, and violet, will appear in the spectrum in the order of their initials; red being the least refracted and lowest, and violet the most refracted and highest, in the series of colors.

Herschel, in his Treatise on Light, thus describes these colors formed by the decomposition of a solar ray. "On viewing the spectrum attentively, we perceive that the lowest or least refracted extremity is a brilliant red, more full and vivid than can be produced by any other means, or than the color of any natural substance. This dies away, first into an orange, and then passes, by imperceptible gradations, into a fine pale straw yellow, which is quickly succeeded by a pure and very intense green, which again passes into a blue, at first of less purity, being mixed with green, but afterwards, as we trace it upwards, deepening into the purest indigo. Meanwhile, the intensity of the illumination is diminishing, and in the upper portions of the indigo tint it is very feeble, but is still continued beyond, and the blue acquires a pallid cast of purplish red, a livid hue better seen than described, and which, though not to be exactly matched by any natural color, approaches most nearly to that of a fading violet."

If these seven colors of the solar spectrum be separately submitted to the action of a second prism, they will be refracted, but undergo no further change of color; thus showing them to be simple or primary colors.*

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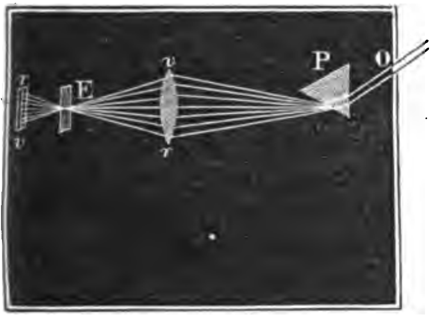
* Some ingenious experiments by the eminent optician, Dr. Brewster, go far towards proving the existence of only *three* primary colors, namely, *red*, *yellow*, and *blue*; the other four colors of the solar spectrum being formed by an intermingling of these three.

Order of the colors of the solar spectrum? Which color of the spectrum is refracted most, and which the least? Describe these different colors. If these seven colors be separately submitted to the action of a second prism, can they be further decomposed?

288. *By reüniting these seven primary colors of the spectrum, white or solar light may be produced.* — This may be effected by an arrangement seen in Fig. 245. Let the various colors of a solar ray, decomposed by the prism, P, fall on the double-convex lens, *v r*, by which they will be converged and made to unite at E. If, now, a screen be held at E, a small *white point of solar light* will be seen. Upon removing the screen to *r v*, the colors of the spectrum will be again seen in an inverted order, from that formed at *v r*. A concave mirror may be substituted for the lens, and the colored rays converged to a point with the same result.

Fig. 245.



By dividing a circular disk into seven sectors, and painting these with colors most nearly approaching the prismatic hues, and then causing this disk to revolve rapidly, as in § 246, instead of either color there will be visible only a grayish white, caused by the blending of the seven primary colors on the retina of the eye. The impossibility of obtaining perfect imitations of the prismatic colors, renders the mingling of artificial spectra an impure white.

289. *Achromatic* Lenses.* — Light, in its passage through different substances, undergoes different degrees of dispersion,

* ἀ, without, *χρῶμα*, color.

Result of reüniting these prismatic colors? How may this reünion be effected, as shown by Fig. 245? If a disc on which are painted the seven primary colors be rapidly revolved, what will be the result? Why cannot a pure white be obtained in this case? What is said of the dispersion of light in its passage through different substances?

or separation into its elementary colors. Thus, a ray traversing a prism of *flint*-glass will have its red and violet colors separated on a screen *twice* as widely as those of a ray passing through a similar prism of *crown*-glass, while the refracting power of both glasses are very nearly equal. Thus we say that the decomposing or *dispersive* power of flint-glass is twice as great as that of crown-glass.

Every simple lens, of whatever substance made, will have a different focus for every different color of which a solar ray is composed; the focus of the red ray lying further from the lens than that of the violet. It is from this cause that the images of such lenses appear more or less impure, or bordered with colored edges, when we look through them at the print of a book, for instance.

Lenses which refract light, without at the same time decomposing it, are termed *achromatic* lenses. To prepare such was for many years the *desideratum* of opticians. Achromatic lenses were at length obtained by combining lenses made of different kinds of glass. Such a combination is seen in Fig. 246, where a convex lens of crown-glass is united with a concave lens of flint-glass so as to destroy each the dispersive power of the other, and produce no dispersion at all, while at the same time the converging power of the convex lens is preserved. Thus, the light passing through these suffers convergence without dispersion.

Fig. 246.

290. The *Rainbow* is a result of the decomposition of the solar rays by the drops of rain, and the separation of these rays into the elementary colors of which they are composed. This consists of a brilliant-colored arch spanning the heavens

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Illustrate this by prisms of flint and crown glass. Will a single lens converge all the primary colors of a solar ray to the same focus? What are Achromatic Lenses? How may such lenses be made as seen in Fig. 246? How is the Rainbow caused? Of what does this consist, and where formed?

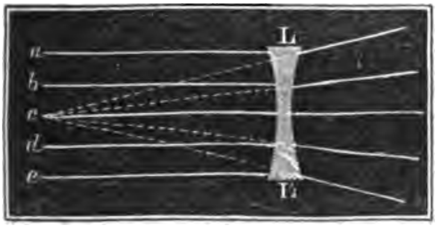
focus. With lenses of the same refracting medium this focus will vary according to the curvature of the sides.

If the rays falling on the lens, L′ L, be *converging*, their focus will be nearer the surface of the lens than F′. If, on the other hand, they be *divergent*, as from the point, *r*, they will have their focus at a point, F, farther from the lens, than that for parallel rays.

284. The rays of light traversing a double-convex lens are not all converged to the same point on the axis. This defect is remedied in a good degree by having the lens of a parabolic form. In the common form of the lens, those rays which pass through it near its edges are converged to a focus nearer the surface of the lens than those which traverse it more nearly parallel with the axis. Such varying of the focal points for rays traversing the lens at different distances from the axis, is termed the *spherical aberration* of the lens. To avoid this aberration in lenses employed for optical purposes, a meniscus (Fig. 240, C) is used with the double-convex lens, by which the rays are made to converge uniformly to a single point.

285. *Rays falling on a double-concave lens are rendered more divergent after than before passing through the lens.* —The parallel rays, *a*, *b*, *c*, *d*, *e*, Fig. 242, falling on the double-concave lens, L L′, after passing through this, are made to diverge as though proceeding from the point, *c*. So convergent rays are rendered less convergent, or even parallel.

Fig. 242.



How will be the focus of diverging and converging rays incident on L′ L? What is said of the rays traversing a double-convex lens? How is the aberration of light in such cases remedied in good part? The course of rays of light traversing a double-concave lens? Explain Fig. 242.

after undergoing decomposition and suffering two refractions and one reflection; each drop, in a vertical series, transmitting to the eye a particular color according to its position and the angle which it makes with the imaginary line passing from the sun through the eye to the centre of the circle; thus forming a bow of prismatic colors around this line or axis, bounded upon the upper side by the red, and upon the under by the violet rays (§ 287).

When the solar rays enter the rain-drops from beneath, as at *v r* in the figure, they are refracted to the back of these drops as before, but, instead of a single reflection, they suffer *two reflections*, and emerge from the upper side of the drops, presenting to the eye a second bow exterior to the first. The order of the colors of this secondary bow will be reversed and much fainter than in the primary, owing to the rays having undergone *two* reflections instead of one; each reflection and refraction serving to disperse or absorb a portion of the light, and so render the colors less brilliant than in the primary or inner bow.

291. *Polarization of Light* is that peculiar change which light undergoes when reflected from certain surfaces at particular angles, or when transmitted through certain crystals, as Iceland spar.

If, for example, rays of light fall on a glass plate blackened on its back, so that its surface shall make with these an angle of 54° 35′, these rays will be reflected according to the usual laws. But if these reflected rays fall on a second and similar glass plate so as to make with its surface also an angle of 54° 35′, they will be reflected from this second surface only in certain positions of the plate. Thus, if this second plate be revolved so as to keep its parallelism at two points in its revolution, it will

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Explain the course of the rays of light in producing the secondary or outer bow. Why are the colors of this secondary bow less brilliant than those of the primary? What is meant by Polarization of Light? Illustrate this in the case of two glass plates blackened at their backs.

reflect the light from the first plate as usual, while at two other points this reflection will wholly cease. In this case the rays by reflection from the first plate undergo a peculiar modification, whereby they deviate from ordinary light in respect to their laws of reflection. Such rays of light are said to be *polarized*.

292. If we place a crystal of Iceland Spar on the letters of a book, for instance, they will *appeur double*, owing to the rays of light in their passage through the crystal having undergone a *double refraction;* so of other objects viewed through it. If we examine, through a plate of *tourmaline*, the two images seen through the Iceland Spar, we shall find that both rays are *polarized;* for, as we turn the tourmaline plate, these rays will be transmitted through it only in certain positions of its revolution; the images alternately appearing and disappearing.

293. *Calorific Rays.*—Light and heat are separate and independent agents. This may be shown by placing a highly sensitive thermometer in the different rays of the solar spectrum (§ 287), when it will be found that the yellow ray, which is the most luminous, is far from being the hottest ray of the solar spectrum, while the red ray, which yields comparatively little light, produces a degree of heat exceeding that of any of the other primary rays.

If the thermometer be carried a little below, and just out of the red ray, into the darkened space, it will show a considerable increase of heat, thus proving the presence of a heating ray in solar light, independent of the luminous principle.

294. *Chemical Action of Solar Light.*—The effect of solar light, in producing chemical changes in certain substances, has been known for ages; but not until within a comparatively recent period were the nature of these changes, and the precise manner in which they are effected, known.

What is said of the effects of Iceland Spar on light traversing it? Are light and heat independent agents? How shown to be such?

Chlorine and hydrogen gases may be mixed together, and kept in a *dark room*, for any length of time, without uniting or suffering the least change; but if, when thus mixed, they be exposed to the clear light of the sun, they will be made to unite rapidly and produce an explosion, when a strong pungent acid (hydrochloric acid) will result. Solar light also promotes the union of the oxygen of air with the carbon and hydrogen of organic substances: hence the darker hue and substantial character of vegetables reared in sunlight compared with those grown in the shade.

The chemical effects of solar light are most remarkably seen in its action on certain salts of silver. Thus, paper covered with a thin coating of chloride of silver — a white salt — rapidly changes its color, and becomes blackened when exposed to sunshine; and if any opaque body, as a leaf, or piece of figured lace, be placed upon this paper before exposing it, the portions of the paper where the sun's light is intercepted will remain unchanged, leaving an exact copy of the object. Upon removing the object, the picture rapidly changes, and the whole surface of the paper becomes uniformly black.

Such impressions, made on paper suitably prepared, and then by certain subsequent appliances rendered permanent, constitutes the PHOTOGRAPH or CALOTYPE art.*

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* We have been kindly furnished with the following modern process for taking photographs and daguerreotypes, by Mr. John A. Whipple, of this city. Mr. Whipple is an artist who has acquired a distinguished reputation by the extraordinary success which has attended his efforts as a photographer and daguerreotypist.

Photographs are taken either on glass, or on paper of the finest quality and most compact material. The compound spread upon these to form a surface sensitive to light is prepared as follows: Collodion, a substance prepared by dissolving gun-cotton in alcohol and ether (six parts alcohol and eight of ether), is mixed with bromine and iodine in the proportion of three grains of iodine and two of bromine to about an ounce of collodion; this compound is then spread evenly on the surface of the glass or paper; the surface, thus prepared,

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Chemical effects of solar light, how shown? What surfaces are particularly sensitive to this? In what does the photographic art consist?

295. *The Daguerreotype.*—This is a process by which solar light is made to paint the images of objects on highly polished metallic surfaces, instead of on paper or glass, as in case of the calotype just referred to.

This method of taking pictures is also due for its success to the chemical action of light on surfaces rendered sensitive by a delicate covering of iodide, cyanuret of silver, or some other substance easily changed by the presence of sunlight.

When such a surface, properly prepared, is suddenly exposed in the *camera obscura*, it has speedily impressed on it an exact outline image of the object or objects before it; the light from the darker portions of the object, acting less upon the sensitive surface, leaves a negative picture of those portions, while that from the lighter portions, or from the spaces where it is not interrupted, produces a further action, and leaves a darker or positive impression. Thus, portraits, artificial views, landscapes, etc., are sketched by the solar rays with a precision and accuracy far exceeding that from the pencil of the most skilful artist.

In this process, the scene presents only a light and a shade. Efforts have, however, been made to paint and fix the *natural colors* of objects sketched in the camera. This has been effected in part, and is known as the *Hillotype* process, from the name of the discoverer, Mr. Hill. At present these colors are made to appear upon the paper or plate, but gradually fade away and disappear under the continued action of light and air. That

is then immersed in a bath containing a solution of nitrate of silver (thirty grains nitrate of silver to one ounce water), where it remains until it acquires a brownish color, or until the greasy appearance is removed, when it is carefully screened from the light, and subsequently placed in the camera-box.

When the person or other object of which a picture is to be taken is arranged at the proper distance, and in a desirable position for forming a suitable image, the slide or screen of the camera-box is suddenly raised, and the light from the object allowed to fall on the sensitive surface. An imperceptible image will be formed in from one-tenth of a second to three minutes, the

Describe the Daguerreotype process. What is the Hillotype?

the efforts now made by the French artists as well as those of our own country, will soon prove successful in rendering permanent the natural colors of objects painted in the camera, we cannot doubt.

Thus, when the delicate expressions of the countenance, the minute and varied outline and changing hues of the landscape, shall be sketched and painted by that most perfect of artists, the sun; when thought shall speed its way from continent to continent, borne with the timeless flight of the lightning, then may be realized in some good degree the full force of the maxim, "Truth is stranger than fiction."

time varying with the degree of light and sensitiveness of the surface; the picture is then developed by pouring over the surface of the glass or paper a solution of sulphate of iron (copperas), of the strength of 8 or 10 Baume's hydrometer, mixed with about one-third its bulk of acetic acid. To fix the picture, the surface is finally washed with a solution of hyposulphate soda, when, after drying thoroughly, it is ready for the frame or case.

Daguerreotypes may be taken by the following process. Smooth and even plates of sheet copper, cut of the proper form and size, are silvered by galvanism. (See § 205.) This coating of silver is then scoured with a mixture of ammonia, alcohol and rotten-stone, and afterwards receives a bright polish on a buff-wheel by means of rouge. It is then dipped in a solution of cyanuret of silver, and subjected for two or three minutes to the galvanic process, when it receives an exceedingly delicate coating of silver; after rinsing off the residue with pure water, and drying over a spirit lamp, it receives a second polish on a buff-wheel. This surface is now placed over a vessel, upon which it fits, and is exposed to the vapor of iodine until it assumes a color between that of lemon and orange; it is then placed over a second vessel containing bromide of lime, heated to 212° F., until the surface acquires a pink color, after which it is again exposed to the vapor of iodine for about one-third the time of the first exposure to this. The plate is now ready for the camera-box, in which, screened from light, it is placed, and the picture taken, as in the photograph process just described. No image appears, however, until the plate has been placed over the vapor of mercury, heated to 212° F., in an iron box, — the time of its exposure to this vapor varying from one-half to three minutes; if exposed too long, the picture will be light and faint; if for too short a time, it will appear too dark. The process of fixing the picture is the same as with the photograph.

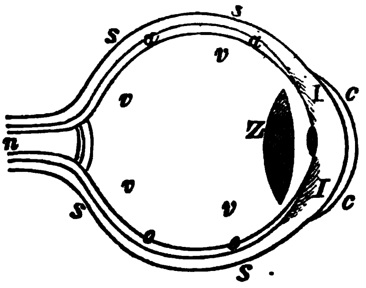
What is said of the probability of being able to fix the colors thus taken?

THE EYE.

296 The eye is that organ of sense which conveys to the mind an image of the external world. Its superior importance may be understood by considering the vast amount of ideas it presents to the mind. By it we are enabled to judge with great readiness and precision of the magnitudes, forms, motions, distances, and positions, of the endless variety of objects which come within its scope. The eye is the most perfect of all optical instruments, and a knowledge of its structure is necessary for comprehending those artificial structures which the ingenuity of man has devised as aids to vision.

297. *The Structure of the Eye.*—The human eye is of a form approaching a sphere, and is placed in a bony cavity at the side of the upper portion of the nose. This consists of an assemblage of lenses so arranged as to concentrate the light from each point of external objects on a delicate tissue of nerves called the retina, there forming an image or exact representation of the various objects perceived by the mind. Fig. 248 presents an enlarged sectional view of the different parts which compose the human eye. The outside covering, S S S S, is the *sclerotic coat*, a tough white membrane commonly known as the *white of the eye.* In the front of this sclerotic coat is a circular transparent opening, having a clear, horny covering, *c c*, projecting somewhat beyond the other portions of the eyeball. This is called

Fig. 248.



What is said of the Eye, and what does it convey to the mind? What is said of it as an optical instrument? Where is it placed? Of what does it consist? What is the retina? What is the sclerotic coat, and how situated?

the *cornea*, and incloses on one side a small chamber filled with a transparent liquid, known as the *aqueous humor*. The form and consistency of this aqueous humor is just what is required for aiding in converging the rays passing through it to a focus at the precise point necessary for distinct vision.

Within this chamber, and partly dividing it, is the *iris*, I I, a circular opaque screen or diaphragm, with a round and apparently dark opening in its centre, called the *pupil*. It is the iris which determines "the color of the eye," as gray, blue, or black, and, by its contraction and expansion, increases or diminishes the size of the pupil, and so regulates the quantity of light admitted to the retina. In the posterior part of the chamber containing the aqueous humor, is the *crystalline lens*, Z, which is a double-convex lens, exhibiting in its form and composition a wonderful contrivance for preventing that spherical aberration, to which convex lenses are usually subject.

The cavity, *v v v v*, behind the crystalline lens, is occupied by the *vitreous humor*, a transparent gelatinous fluid, much resembling the white of an egg. Lining the inner surface of the sclerotic coat, is a dark membraneous substance, *a a*, called the *choroid covering*, which serves to absorb the light as soon as it has acted on the retina, and thus prevents internal reflections, and consequent confusion of vision.

The *retina* is a delicate network of nerves spreading over the choroid surface, and appears to be only an expansion of the optic nerve, *n*. It is upon this that the *images* of external objects are cast, of which an impression is conveyed by the optic nerve to the brain.

298. *The images of external objects are inverted on the retina.* — The refracting mediums of the eye act on the rays

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The cornea? The aqueous humor? What is said of the aqueous humor? What is the iris? What is the crystalline lens, and where situated? What is the vitreous humor? What is the choroid covering, and its use? Describe the retina. How are the images of external objects formed on the retina?

passing through them, similar to a convex lens (§ 283), causing an inverted image of objects to be formed on the retina. Fig. 249 will serve to show the course of light proceeding from an object to the eye. These rays are seen to be converged by the humors or lenses of the eye, and cross just behind the crystalline lens, so as to form a minute inverted image on the retina.

This may be shown by taking the eye of an ox, or other large animal recently killed, and removing the posterior portions so as to lay bare the choroid membrane. If the eye, thus prepared, be fixed in a screen, and a lighted candle be placed before it, at the distance of fifteen or twenty inches, a minute inverted image of the candle will be seen through the retina, as if produced by a double-convex lens on a screen of ground glass, or oiled paper.

299. *The eye possesses the remarkable power of adapting itself to objects at varying distances.* — We have already seen that the focus for light of a convex lens is constantly changing with the distance of the object and the angle which the rays proceeding from it make when incident on the lens. Hence, to preserve the focus at the same distance from the lens, it is necessary either to vary its form and power of refraction, or its distance from the object.

In the eye, this uniformity of the focal distance is most accurately preserved by an involuntary change in the convexity of the refracting mediums, thus varying the form of these mediums with the angle of the incident rays, and so causing the focus of the light to fall exactly at that point necessary for forming a perfect image on the retina. This power of the eye to adapt itself to objects situated at different distances from it, may be proved by the following

Experiment. — Let a small black spot be made on a thin transparent plate of glass, placed about twelve inches from the

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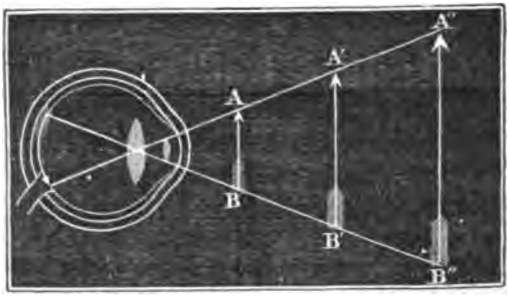
How may the course of light through the eye and the images formed on the retina be shown? What is said of the power of the eye for adapting itself to objects at varying distances? Give the experiment illustrating this.

eye. If the eye be directed to it, the spot will be seen, as well as distant objects visible through the glass. Let the attention be earnestly directed to the black spot, so that a distinct perception of its form may be produced. The objects visible at a distance will then be found to become indistinct. But if the attention be directed more to the distant objects, so as to obtain a distinct perception of them, the perception of the black spot on the glass will become indistinct.*

300. *The apparent size of an object depends on the size of the visual angle under which it appears.* — Let A B, A′ B′, A″ B″, Fig. 249, be three objects differing in their vertical heights, in proportion to their distances from the eye. As each subtends the same visual angle, their *apparent* heights will be equal. Thus, a small gnat near the eye may cover the same angle and appear equal in size to an eagle at a distance.

Fig. 249.



301. *The eye supplies no direct perception of the magnitude and distance of objects; these being determined by an exercise of the judgment based on experience.* — Thus, we judge of the height and distance of a church-steeple, or

* Lardner.

Upon what does the apparent size of an object depend? How does Fig. 249 show this? What is said of the eye in reference to the magnitude and distance of objects? How do we judge of the height and distance of any object, as a church-steeple for instance?

tower, by comparing these with known objects which intervene. When no such objects stand between the eye and the distant body, whereby a comparison may be made, we often err greatly in our estimates of these. This is especially true in viewing objects on the ocean.* Hence it is, also, that the sun and moon appear larger when rising and setting, than when at the zenith; these, at such positions, being compared with the intervening objects, whereby a false estimate of their visual dimensions is obtained.

On the contrary, we often judge an object to be much smaller than the reality, when viewed alongside some body of surpassing dimensions. Thus, a first-class merchant-man may be estimated no larger than a small barque when seen moored beside a three-decker ship-of-the-line; or dwellings of ordinary size, viewed in contrast with St. Peter's church at Rome, or the Capitol at Washington, may seem like mere cottages.

302. NEAR AND FAR SIGHTEDNESS *are occasioned by too great or too slight convexity of the refracting medium of the eye, whereby rays of light are brought to a focus before or behind the retina.* — When the convexity of the cornea is too great, as in cases of near-sightedness, the eye has not the power of diminishing this convexity, sufficient to throw the focus of rays from objects making a small angle with it back upon the retina. In such case only a confused image is formed on the retina. To prevent this, it is necessary to increase the angle which the rays make upon entering the eye, either by a use of

* The dim perception of vessels seen through a fog often deceives the judgment in regard to their size, since the appearance, through such a medium, leads us to suppose them at a much greater distance than they really are. Thus, an ordinary sail-boat, under such circumstances, has been often mistaken for a sloop or schooner; these, in such cases, are said by sailors to loom up.

Where is our judgment in regard to distance and magnitude especially liable to err? What is said of our judgment of the size of objects in contrast with those much larger? How are near and far sightedness occasioned? In case of near sight, how is the light converged by the crystalline lens? How may this be prevented?

small double-concave lenses (§ 285), called *spectacles*, or by bringing the object nearer the eye.

On the other hand, when the convexity of the cornea becomes too much diminished, as in old age, the rays are not converged to a point sufficiently soon, but have their focus *behind* the retina. To remedy this defect by increasing the convergence of the light behind the crystalline lens the angle of the rays incident on the lenses of the eye must be diminished; this may be effected, either by holding the object, as a book, for instance, at a distance from the eye, or by the use of spectacles with convex lenses.*

303. *The impression of a visible object on the retina lasts for an appreciable time after the object is removed.*— If a fire-brand be made to revolve rapidly before the eye, an entire circle of light will be seen; for the impression made on the retina, by the light at any point of the circle, remains until the brand returns to that point again.† So, also, of lightning

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* Defective sight may arise from various causes. Thus, near-sightedness may be caused by a too great convexity of the cornea or the crystalline lens, or from too great a difference of density between the aqueous and the crystalline humors, or between the crystalline and the vitreous humors, or both of them; or it may be caused by defects both of the form and the relative densities of the humors. Sight is sometimes injured or well-nigh destroyed by the crystalline humor losing its transparency in a greater or less degree, and thus preventing the light from reaching the retina, or from reaching it in a proper state to form an image. This is seen in cases of *cataract*. Such a defect may be often remedied by removing the crystalline humor, and leaving the light to be converged by the aqueous and vitreous humors only. If these be not sufficient to converge the light, they may be assisted by convex spectacles.

† The impression of light on the retina lasts from one-seventh to one-tenth of a second, varying according to the vividness of the light producing the impression. The state of the illumination of the surrounding space also varies the time of the impression. A luminous object in a dark room produces an impression more lasting than the same object in a light room. This is probably due to the greater sensitiveness of the retina when in a state of repose, than when its entire surface is excited by surrounding lights.

How is defective sight in old age produced, and how may this be remedied? What is said of the impressions on the retina after an object is removed? Why does a fire-brand whirled in the air produce a circle of light?

and meteors which exhibit long luminous lines; the impression of the light from the first part of their course not being removed before that from the last is received.

The *Phantasmascope*, an optical toy, acts on this principle. This consists of disks, bearing on their margin a variety of figures, which are so related to each other, that each succeeding figure shall afford a continuation of the preceding, and the whole taken together, when put in rapid revolution, shall exhibit a single figure, performing some singular or amusing feat. Thus, the figure might commence with a player, holding a violin and a bow which is just beginning to draw; the second view might represent the bow as drawn a little; the third, still more; and the whole views would then exhibit the usual motions of the bow. In the same manner are performed dances, feats of horsemanship, and the like.*

304. *Spectral Colors.*—When the eye has gazed fixedly for some time on an object of a particular color, strongly illuminated, upon turning suddenly to a dark or white wall, it will continue to see an image of the object, but of a color quite different from the original. This image is called an *ocular spectrum*, and the colors it presents *accidental colors.* Thus, if a bright-red figure painted on a dark surface be intently watched for a few moments, and then the eye turn to a white wall, the same image will continue and appear on the wall, but, instead of red, it will appear of a bluish-green color, or that color complementary to the original color of the object. So, if it be yellow, the spectra will appear of a deep violet.

These complementary colors, at first quite distinct, gradually fade, passing into others, until the spectral image vanishes. This phenomenon is occasioned by the eye becoming partially para-

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* Olmsted's Philosophy.

Describe the operation of the Phantasmascope. When are ocular spectra produced? What are these colors produced called? What relation do the colors seen under these circumstances sustain to each other? Illustrate this. How is this phenomenon occasioned?

lyzed by the dazzling effect of the light from the object, and so indifferent to the particular tints it presents, but more sensitive to those colors most widely opposed to these. It is, therefore, that the eye, in the case of the red figure, perceives its complementary color, green, and continues to perceive it until the retina again recovers its sensibility for red light.

305. *Defect of vision from an inability to distinguish certain colors.*—Persons are occasionally met with, whose vision, although sound in all other respects, is singularly defective in the power of distinguishing particular colors of the spectrum.

Sir David Brewster relates the case of a shoemaker, by the name of Harris, who always mistook orange for grass-green, and light-green for yellow, and from infancy was unable to distinguish the cherries of a cherry-tree from its leaves, so far as color was concerned.

Another amusing instance is given of a tailor, who confounded green with red, and who one day, by mistake, repaired a coat, of dark-green color, with a piece of cloth of scarlet color.

Such states of vision are attributed by Sir J. Herschel to a defect in the sensorium, by which it is rendered incapable of appreciating exactly those differences between rays on which their color depends.

OPTICAL INSTRUMENTS.

306. *The Microscope.**—This instrument, designed for aiding the eye in perceiving minute objects, may be regarded as among

* *Μικρὸς*, small, *σκοπεω*, to see.

What is said of defects in the vision of some persons in regard to their ability to distinguish colors? Case of the shoemaker? The tailor? How does Sir J. Herschel explain the cause of these singular defects? For what is the Microscope designed?

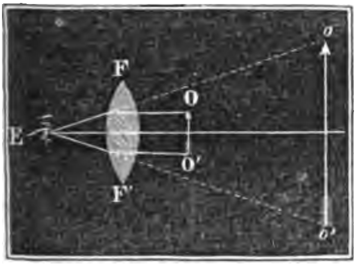
the most remarkable achievements of modern art, since its discovery has brought to view a new world of being, and disclosed processes in nature equally wonderful and important.

We have already seen (§ 300) that the apparent size of objects depends on the angle under which they are viewed, and of course upon their nearness to the eye. When, however, an object approaching the eye reaches a certain point, its rays meet this at angles, too diverging to be collected by the crystalline lens on the retina, and vision begins to grow imperfect. This point is known as *the limit of distinct vision*, and is usually about *five inches* distant from the eye.

Every instrument, therefore, which will admit of viewing objects nearer than this limiting angle, may be regarded as a microscope.

307. A *Simple Microscope* is merely a convex lens, of short focal distance, by which the rays from near objects may be converged to the eye, so as to render these visible. The magnifying principle of this microscope may be illustrated by Fig. 250.

Fig. 250.



308. Let O O′, Fig. 250, be a minute object placed before the double-convex lens, F F′, at or just without its principal focus, but too near the eye to be seen by it without artificial aid. The rays which fall on the lens from O O′, and every intermediate point of the object, will be converged, and enter the eye, at E, causing an image of the object, greatly

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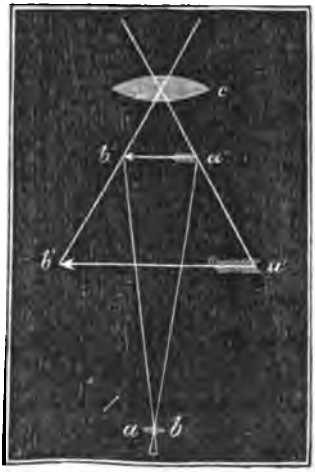
How may this instrument be regarded? Why cannot minute objects near the eye be distinctly perceived? What is meant by the limit of distinct vision, and how far is this usually from the eye? What use does the microscope serve? What is a Simple Microscope? Explain the manner in which the microscope, as seen in Fig. 250, enables the eye to distinguish minute objects very near it, by magnifying their apparent dimensions.

magnified, to appear at *o o′*. The apparent magnitude of the image, in such a case, will depend on the angle at which the rays from the object enter the eye after traversing the lens; hence lenses of high refractive powers and short focal distance magnify most. Such can be used for examining only the most minute objects placed very near the eye, since their field of vision is extremely limited, and covered by objects of small extent.

309. The *magnifying power of a lens* * may be determined very nearly by dividing the limit of distinct vision by the distance of the object from the centre of the lens. Thus, in Fig. 250, if we suppose the former to be five inches, and the distance of the object from the centre of the lens, $\frac{1}{10}$ of an inch, then will the magnifying power be as $\frac{1}{10}$ to 5, which is as 1 to 50, or as 1 to 2,500 in surface. That is, the length of *o o′* will appear fifty times that of O O′.

Fig. 251.



The Magic Lantern, Solar Microscope, and Camera Obscura, are all different forms of the simple microscope, and will be subsequently described.

310. The *Compound Microscope* is formed by arranging a second lens so as to magnify the *image* of the object formed by the simple microscope or single lens. Thus, instead of the object itself, the *image* of that object is examined by the eye. Fig. 251 shows the principle

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* The diamond affords the most perfect material for magnifying purposes;

What kind of lenses magnify most? What class of objects can only be examined by such lenses? How may the magnifying power of a lens be determined? Explain this. How is the Compound Microscope formed? Explain this from Fig. 251.

of the Compound Microscope. The object-glass, *a b*, is fixed in the lower extremity of the tube, near the minute object placed just below. This presents a magnified and inverted image of the object, $a'' b''$, at the focus of the eye-glass, *c*. By this second lens, or eye-glass, the *image* formed is magnified, and brought to the eye, situated above and near *c*, so as to appear at $a' b'$ of surprising dimensions.

Fig. 252.

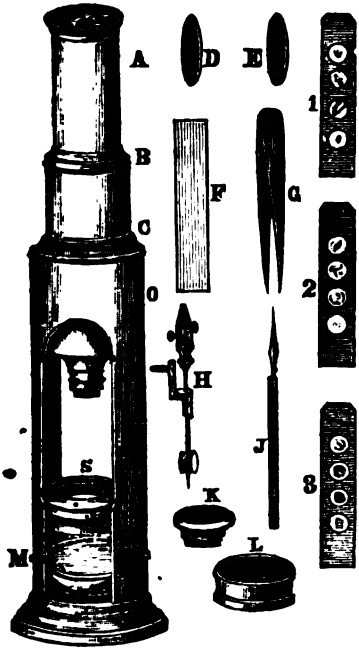

Fig. 252 presents such a microscope complete in all its parts. The tube, A, contains in its upper part the eye-glass; this tube slides in a second, B, in the lower extremity of which is fixed the small object-glass; B also moves in the stand C. Thus, by such a movement of these tubes, the lenses in them may be adjusted to the proper distance from each other, and the object to be examined, which is placed at S. M is a mirror for reflecting the light from the sun, or a lamp

for, owing to its high refracting power, it enables the eye to see minute objects at a large angle. The diamond, moreover, causes but a comparatively *slight aberration* of the light passing through it, while its *dispersive* power, or power of decomposing light into its prismatic colors, is but trifling, being nearly achromatic. For these reasons it is peculiarly adapted to magnifiers for high powers. The sapphire, garnet, and quartz crystal, are also well adapted for magnifiers of high powers.

Describe the parts of the Compound Microscope when complete, as in Fig. 252.

upon the object at S, and so illuminating and rendering it more distinct. This mirror turns on pinions, and can be fixed at any desired angle. The various appendages to this compound microscope are also shown in the figure. D, E, are eye-glasses of different powers; F, a glass plate, on which minute objects for examination may be laid; G, a pair of delicate tongs, for taking up small objects; H, a pair of pincers fixed at one end of a wire, to the other of which is attached a small ivory capsule for holding various objects, the whole turning on a pinion, fitting into a hole in S; J, a delicate point for taking up minute objects; K, the eye-piece for holding the eye-glass; L, a receiver for liquids; 1, 2, 3, small objects fixed on glasses set in sliders, which slide between the springs of S.

311. No instrument of human contrivance has done more than the microscope to enlarge the boundaries of knowledge, and unfold to the mind the exquisite skill and perfection displayed in creation. It places us in the midst of a world before invisible, and which, like a new creation in the freshness of beauty, stretches away in enchanting prospects on every side. It shows that beyond the limits of our unaided vision all is instinct with life, and replete with harmony, skill and wise design.

The most common substances, which afford but little if any interest to the unaided vision, under the microscope become often objects of the highest interest and instruction. Thus, a single grain of marl, for instance, is seen to be composed of myriads of flinty skeletons of minute creatures, perfect in their organization, and once replete with life and activity, while a single drop of liquid may exhibit millions of living animalculæ, which appear like huge monsters swimming about and sporting at will, as in a vast sea.* By means of the microscope, the characteristics and habits of many minute insects, whose operations have an important bearing on the convenience and comfort of man, may be learned, and their injurious results thereby guarded against. In a word, this instrument enables our vision to explore fields of beauty and variety before undiscovered, but replete with interest, as bearing upon our physical well-being and happiness.

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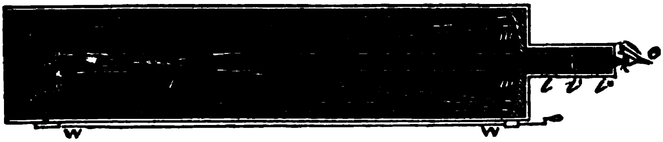
* According to the microscopic researches of Ehrenberg, a species of slate,

What is said of the Microscope in reference to human knowledge? Under this instrument, what do some of the most common substances present? Give illustrations.

312. The *Telescope** is an instrument for viewing distant bodies on the earth or in the heavens. The kinds employed are two, known as the *reflecting* and the *refracting* telescopes.

The Reflecting Telescope.—Fig. 253 exhibits the internal arrangement of the more common form of this telescope, known as the Gregorian Telescope. In a large open tube is fixed a highly polished metallic concave speculum,† *m m′*, having a circular aperture in its centre. The rays, *r r′*, entering

Fig. 253.



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found in Bohemia, consists almost entirely of the skeletons of minute animals, of which *forty-one thousand millions* are found to lie entombed within the space of a single cubic inch. A species of marl, existing extensively in various sections of the United States, is found to be composed almost wholly of the bodies of infusoria, well-nigh exceeding in numbers the bounds of credibility. So small are these minute creatures, that a thousand might swim side by side through the eye of a needle. This marl, thus composed, becomes one of the most fertilizing products to be found, and is accordingly extensively used as a manure.

* *Τῆλε*, at a distance, *σκοπεῖν*, to see.

† A *speculum* is a reflector formed of highly polished metal. A *mirror* is a reflector made of glass, usually coated on its back with an amalgam of tin and quicksilver.

The uses of the Telescope? The kinds employed? Describe the Reflecting Telescope, as shown in Fig. 253.

through the open end of the tube, are reflected by this speculum, so as to form an *inverted* image at *i*, the focus of the small concave mirror, *s*; by this small mirror a second *erect* image is formed before the eye-glass, *l*, at *i′*; this image is magnified by the eye-glass, *i″*, and is viewed by the eye, at *e*, the same as in the compound microscope. The second lens, at *l*, is usually interposed for rendering the rays from the small mirror more convergent; this, however, is not necessary; w w, is a rod and screw, connecting with the mirror, *s*, for regulating the distance of this, and adjusting it to the focus of the mirror, *m m′*.

Telescopes of the larger size and higher powers have been usually reflecting telescopes.* These possess some advantages over the refracting telescope to be described, such as the avoiding spherical and chromatic aberration, consequent upon the difficulty of obtaining lenses free from these defects. The reflectors of this form of telescope are made of a parabolic form, which thus greatly improves their powers of reflecting, and converging the light falling upon them, and so renders more distinct the image of the object. In the reflecting telescope, this image is seen erect, and in the same direction with the object.

Fig. 254 presents an external view of such a telescope mounted on a tripod-stand, with a sight attached.

313. The *Refracting Telescope*, for astronomical purposes,

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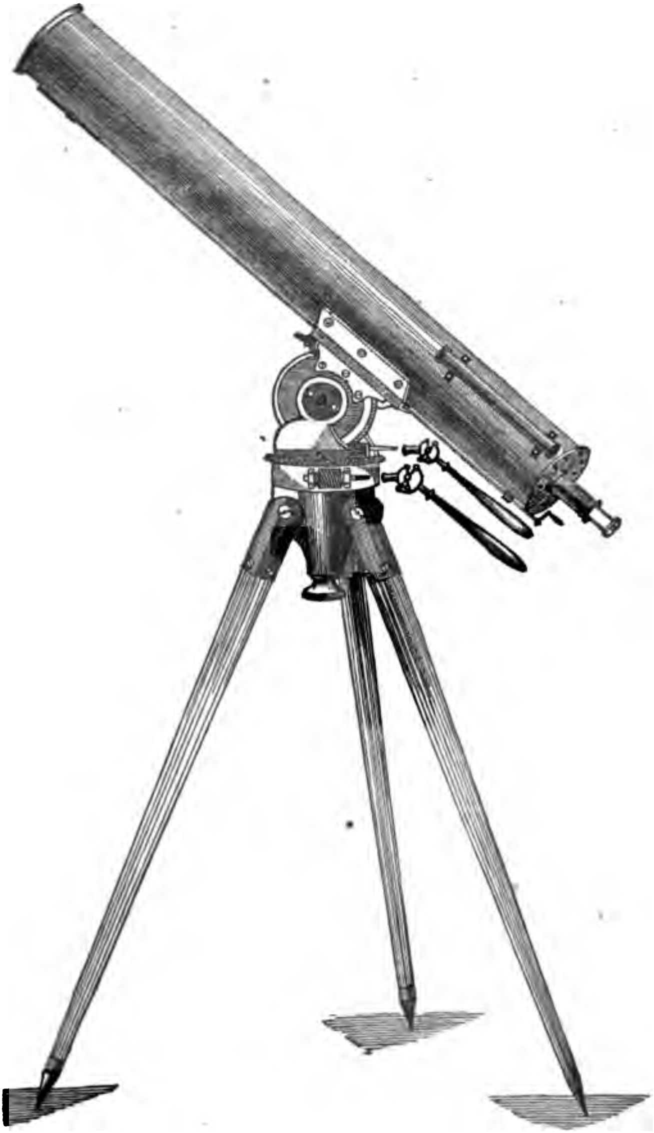
* The great telescope of Sir William Herschel, constructed under the patronage of George III., was a reflecting telescope. The focal length of this was forty feet, and had a speculum 49½ inches in diameter, which weighed 2118 pounds. The second reflector at S, Fig. 253, was dispensed with, and the waste of light by a second reflection thus avoided. The image thus formed was thrown near to the open mouth of the tube, where it was viewed by an eye-glass directly, the observer being seated so as to look into the mouth in front. In this telescope many of the larger stars, as Sirius, appeared with the splendor of the sun.

Lord Rosse's great reflecting telescope was constructed with a speculum six feet in diameter, being otherways of proportionate dimensions.

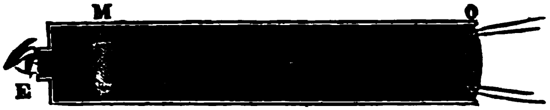
What are some advantages possessed by reflecting over refracting telescopes? How are the reflectors formed? What is said of the image in this? What does Fig. 254 show? How does the refracting differ from the reflecting telescope last described?

Fig. 254.



differs from the reflecting, just described, in having the image before the magnifying-glass formed by lenses instead of mirrors. Fig. 255 shows the internal arrangement of such a telescope, the principle of which is similar to the compound microscope, differing from that in nothing except the proportion of its parts. O is the object-glass placed at the end of the tube, which serves to collect the rays from a distant object, and form an inverted image of the same at o o′, in the focus of the magnifying lens, M; by this it is magnified, as in the microscope, Fig. 251, and appears to the eye at E.

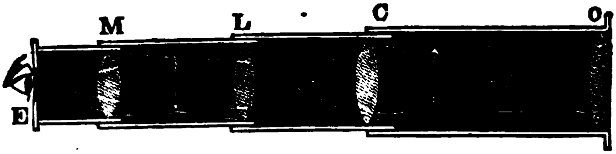
Fig. 255.



314. *The Terrestrial Telescope or Spy-glass.* — As the Astronomical Telescope, last described, presents objects to the eye *inverted*, it is unsuited for viewing terrestrial objects; accordingly, for this purpose, two additional lenses are interposed between the eye and the image, whereby the latter is made to assume an erect and natural position in reference to the eye.

The course of the rays and position of the image in the terrestrial telescope will be readily understood by Fig. 256, where

Fig. 256.

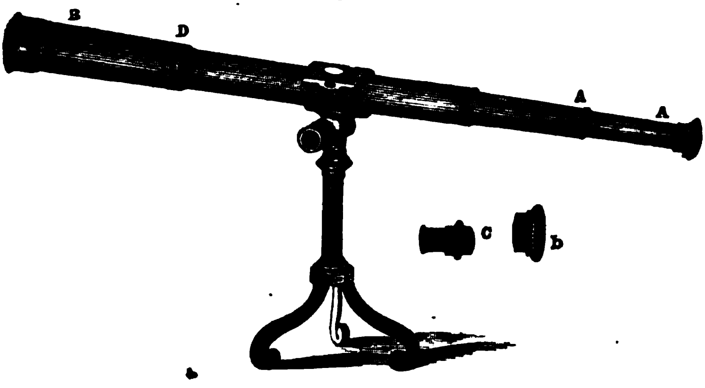


Explain Fig. 255. Why is the Astronomical Telescope unsuited for viewing terrestrial objects? How is this remedied, and the object made to appear upright? Explain the course of the rays of light, and the manner in which the image of the object is seen direct, as shown in Fig. 256.

O is the object-glass and m n the first image formed at the focal distance of the converging lens, C; consequently, the rays from m n, after passing through C, will emerge parallel. These then fall on another converging lens, L, of equal focal length, by which they are again made to converge and form a second image, n m, inverted with respect to the first, but in the same position as the object. This image is then viewed through the magnifying lens, M, by the eye at E, as in the previous figures.

These lenses are fixed in tubes, which slide one within the other, by which each may be adjusted to the correct focal distance. These tubes are better shown by Fig. 257, which presents a view of the *Mounted Spy-glass*. C is for the eye-glass or magnifier, in which magnifiers suited to different eyes may be inserted; b is a shade-glass for protecting the eye against the concentrated light from the lens. The great improvements of late, in the construction of large achromatic lenses (§ 289), have caused refracting telescopes to be more generally employed for astronomical as well as terrestrial observations.

Fig. 257.



315. The magnifying power of the telescope depends on the

What does Fig. 257 show? On what ratio does the magnifying power of the telescope depend?

ratio between the focal distances of the object-glass and the eye-glass. Thus, in Fig. 255, suppose the common focus ten times nearer the eye-glass than the object-glass, then will the instrument magnify ten times; if fifty times nearer, fifty times, and so on. Hence, the magnifying power of the telescope may be increased, either by using an object-glass of small curvature, so as to throw the image to a great distance, or an eye-glass of high curvature and short focal distance. Thus, if the object-glass have a focal distance of twenty-five feet (300 inches, for instance), and the eye-glass or magnifier one tenth of an inch, then will the magnifying power of the telescope be three thousand times in diameter, and nine millions in surface.

Galileo's Telescope.—This is the most simple form of telescope now used, and possesses some important advantages over the refracting telescope, just described. The object in this is made to appear erect, by the use of only two lenses. These lenses consist of a double-convex lens for the object-glass, and a double-concave for the eye-glass; the latter is placed within the focus of the object-glass, so as to magnify its image formed before the crossing of the rays. Owing to such an arrangement of the lenses, these telescopes are comparatively short, and therefore more convenient for many purposes. Opera glasses are telescopes of this form.

According to this how may the magnifying power of the telescope be increased? Give an illustration. What is said of Galileo's Telescope? How does the object in this appear? How many, and what form of lenses? What are Opera glasses?

HEAT.

316. HEAT is the sensation experienced when we touch any object the temperature of which exceeds that of the human body. As in case of light, the principle or essence of heat is unknown; our knowledge of it being confined merely to the effects it produces in matter.

The sources of heat are various, as that from the sun, from combustion, friction, etc. The sun is the chief source from whence the earth is supplied with heat, and thus rendered capable of sustaining the varieties of animal and vegetable life found scattered over its surface. Heat is also freely given out whenever oxygen gas, one of the elements of common air, is made to combine rapidly with a combustible body, as in the burning of the wood and coal of our fires. Friction, caused by rubbing together bodies, as pieces of dry wood,* the hands, etc., excites heat. This is, moreover, produced by percussion, as when metals are hammered upon an anvil, by chemical mixtures, etc.

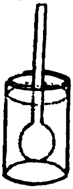
317. *Expansion of bodies by heat.*—Heat exerts an influence counter to molecular attraction or cohesion, and, when diffused through bodies, tends to drive asunder and separate the atoms of which they are composed; hence it is that bodies usually expand, and increase in bulk in proportion to the amount of heat applied. This increase in bulk of bodies, caused by heat, is most clearly shown in the case of liquids and the gases.

* The American Indians, throughout the whole extent from Patagonia to Greenland, formerly procured fire by rubbing together pieces of dry wood until they kindled into a flame. Instances have occurred where whole forests have been burned down, by fires kindled from the violent friction of the branches against each other, caused by the wind.—*Parke's Chem. Catechism.*

What is heat? Do we know anything of the principle of heat? What are some of the sources of heat? The principal source of heat? How is heat related to molecular attraction or cohesion? What is said of the expansion of different bodies by heat?

Experiment. — Pour water or alcohol into a bulb, Fig. 258, having a long tubular neck, so as to cause the water to rise part way in this, and immerse the bulb in boiling water, or apply the heat of a lamp. As the liquid within the bulb becomes heated, it will be seen to expand and rise in the neck, in proportion to the degree of the heat applied.

Fig. 258.



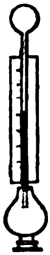
Experiment a. — Invert such a bulb, filled only with air, and place the extremity of its neck in some water. Upon applying the heat of a lamp, the air in the bulb will rapidly expand, and be forced out in bubbles through the water. This expansion of the confined air will be perceptible, with only the heat from the hand applied.

318. The regular expansion of liquids and gases by heat led to the invention of the *Thermometer*,* for measuring changes in the temperature of the atmosphere and other bodies.

The simplest and most sensitive kind of thermometer is that discovered by Sanctorio, in 1590, and called, from the manner of its construction, the *Air Thermometer*.

This is seen in Fig. 259, and consists of a glass bulb, with a long stem entering some colored liquid in the small vessel beneath. From this bulb, a portion of the air is expelled, so as to cause the liquid to rise part way in the stem.

Fig. 259.



A very trifling change in the temperature of the surrounding air will be shown by a corresponding increase or diminution of the bulk of that confined in the bulb, which will cause the colored liquid to rise or fall in the stem. To this stem is affixed a scale graduated to denote the temperature, corresponding to the height of the liquid in the tube.

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* *Thermos*, heat ; *metron*, a measure.

Give the experiment with water or alcohol? With air? The use of the Thermometer? What is said of the Air Thermometer? Describe its construction?

The extreme susceptibility of air to expansion from heat causes such a thermometer, of moderate length of stem, to indicate the changes of temperature within only a very limited range. This was accordingly dispensed with, and thermometers filled with mercury were substituted.

319. The *Mercurial Thermometer* is the form now almost universally used. For filling thermometers, no fluid possesses the advantages of mercury, since it is not only quite sensitive to the effects of a change of temperature, but also expands uniformly, and within comparatively narrow limits.

The common mercurial thermometer consists of a small glass bulb with a stem having a fine bore. This bulb and a portion of the stem are filled with pure mercury, by first expelling the air, as in § 317, Experiment *a*, and then placing the end of the stem in the fluid. As the bulb cools, mercury flows up into the vacant space; when a sufficient quantity has entered, the stem is inverted, and the bulb heated to the boiling-point of mercury, to expel all the air, and the end of the stem then sealed with a blowpipe.

The bulb, thus filled, is then plunged in ice-water, and the point at which the mercury stands in the tube carefully marked; and then again in boiling water, and the point at which the mercury stands in this also marked. These constitute the freezing and boiling points of the graduated scale affixed.

The scales of different thermometers are differently graduated. That of Fahrenheit (the thermometer commonly used in this country) has the freezing-point marked 32°, and the boiling-point 212°; the zero is consequently 32 degrees below the freezing-point. The Centigrade thermometer has the freezing-point marked 0°, and the boiling-point 100°. Between the freezing and boiling points of each thermometer the scale is

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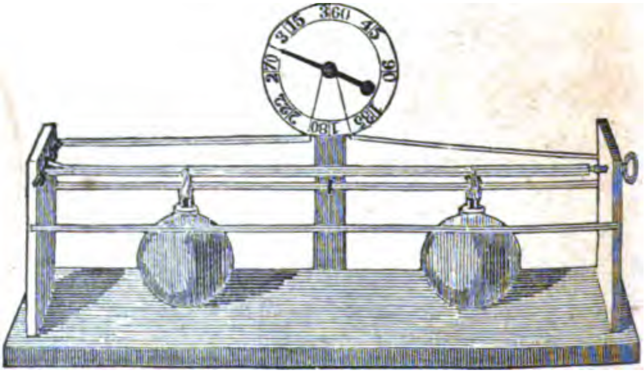
What objections to this form of thermometer? The kind of thermometer now generally used? Why is mercury well adapted for filling thermometers? Describe the manner of constructing the common Mercurial Thermometer? Are the scales of the different thermometers alike? What are the freezing and boiling points of Fahrenheit's scale? Of the Centigrade scale?

divided into the corresponding number of equal divisions, and, as the mercury in the bulb expands uniformly, the temperature is indicated by the point upon the scale against which it stands in the tube.

320. Solids, like gases and liquids, have their dimensions increased by heat. These, however, expand differently with the same degree of heat applied. Thus, 800 cubic inches of iron heated from the freezing to the boiling point of water, become 801 cubic inches; 350 of lead become 351, and so of other solids.

The *Pyrometer*, Fig. 260, is an instrument for indicating with considerable accuracy the expansion of rods of different metals by the same degree of heat. The rod of metal to be tested is placed with one end against a screw, and the other resting against a small pin projecting from a right-angular rod, so attached to the frame as to turn readily whenever there is a pressure against the pin. The free end of this right-angular rod is connected with the revolving hand of a graduated disc,

Fig. 260



How does heat affect the dimensions of solids? Illustrate this in the cases of iron and lead. What is the Pyrometer? Describe its construction and operation, as shown in Fig. 260.

by means of a fine cord passing around its hub, so that, upon the slightest pressure against the right-angular rod, the hand is made to turn. The other end of this cord is attached to a second rod, free to rise and fall, whereby an even balance is maintained. If, now, a rod of any metal be placed between the screw and pin, and the heat of one or more spirit lamps be applied, this will be seen to expand the metal, causing the rod gradually to increase in length, as indicated by the pressure against the pin, and the corresponding motion of the hand. By this means, the different degrees of expansion of the various metals may be readily shown.

In the arts, advantage is often taken of this expansion of metals by heat. Thus, the blacksmith places the tire or band upon the wheel while the metal is hot, so that, upon cooling, it may contract, and draw firmly together the different parts of the wood. So, for a like reason, the rivets for steam-boilers are fixed in their places while heated, which causes them, when cooled, to hold together the overlapping edges with the greatest force.

321. *Heat, like electricity, tends to an equilibrium ;* consequently, bodies heated to a temperature above those immediately surrounding, tend to part with their heat to those surrounding bodies, until a uniform temperature throughout the whole is attained.

Bodies part with their heat in various ways, as by conduction, by convexion, and by radiation. If a piece of heated metal be laid on other cold bodies, the heat rapidly passes from this, by conduction, to these colder bodies, and soon all become of a uniform temperature.

322. *Different bodies conduct heat with different degrees of readiness ;* this power of conduction varies in general with

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What are instances of the advantages often taken of the expansion of metals by heat? What is said of the tendency of heat to an equilibrium? What are some of the ways in which bodies part with their heat? Do all bodies conduct heat alike? How does this usually vary?

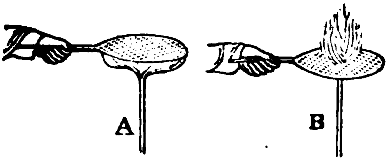
the density of bodies, those more dense conducting it with greater facility than those less dense.

Thus, metals are in general better conductors of heat than stones, stones than wood, and wood than air and the gases. This is illustrated in many of the implements used about a fire, as soldering-irons, pokers, etc., which are usually provided with wood handles for protecting the hands.

It is the superior facility with which metals conduct the heat from the hand, that causes a bar of iron, for instance, to feel colder to the touch than a piece of wood or cloth, while a thermometer will indicate the same degree of heat in each.

Fig. 261 serves to show the readiness with which metals conduct heat. If a wire gauze be held over the flame of a lamp, the incandescent particles, as they come in contact with the wires, will have their heat taken from them so rapidly by the metal, as to become cooled, and so lose their glow upon passing through the wires. Thus the flame will be intercepted, as at A, instead of passing the screen, as shown at B.

Fig. 261.



Of imperfect conductors of heat, common air, a type of the gases, affords one of the best examples. It is from this cause that clothing formed of loose fibrous materials, as wool, furs. etc., which hold between their particles large quantities of air, is warmer than that formed from the more compact fabrics of cotton and linen. It is from a like cause that snow serves to prevent the escape of heat from the ground, and so protects vegetation against the severe frosts of winter; this holding be-

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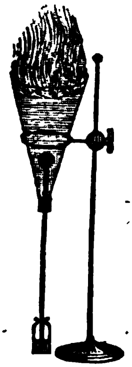
Why are many of the implements used about a fire provided with wood handles? Why does a bar of iron feel colder or warmer to the hand than a piece of wood or cloth? What is said of air as a conductor of heat? Why are furs and woollens warmer than cotton and linen fabrics?

tween its particles a large amount of air, and so forming a very bad conductor of the heat.

323. *Liquids are among the worst conductors of heat.* — Indeed, so slight is their conducting power, that Count Rumford, after a great variety of experiments, was led to infer their perfect non-conducting power of heat. Later experiments have, however, shown them to be conductors of this to a very limited extent. Fig. 262 exhibits an arrangement for showing this. A tunnel-shaped vessel, nearly filled with water, contains a delicate air-thermometer, with its stem passing down through a cork into the small bottle beneath; this thermometer will readily detect the least change in the temperature of the water. Upon the upper surface is poured some ether, which, when inflamed, as seen in the figure, produces a great amount of heat. Such a heat, thus applied, is found not to affect in any perceptible degree the temperature of the liquid immediately below its surface, as may be shown by raising the bulb of the thermometer very near the surface of the water, next the burning ether, when it will still remain unaffected.

Fig. 262.



*Liquids become heated by convexion.** — Thus, in a vessel of water, heated over the fire, those particles of the liquid resting against the heated metal of the bottom become hot and rise, while others above sink down and occupy their place, and in turn become heated and rise, and so the process goes on until all the particles of the liquid are brought in contact with the heated surface. In a similar manner air surrounding a heated body becomes warmed.

324. *Bodies radiate their heat in all directions.* — Radi-

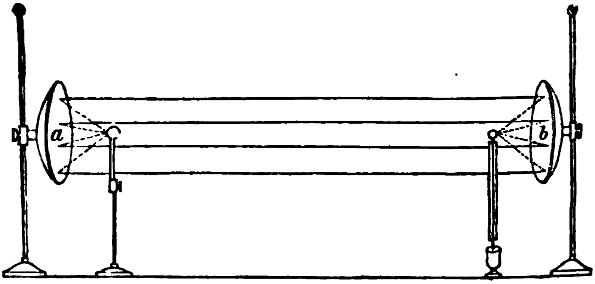
* *Con*, to, and *veho*, to bear.

What is said of liquids as conductors of heat? What is Fig. 262 designed to illustrate? Explain this. How do liquids become heated by convexion?

ant heat follows in most respects the same laws as light from luminous bodies, being emitted in direct lines from all sides of the heated body, and subject to reflection, refraction, and polarization, the same as light. Different surfaces radiate heat with different degrees of facility. Dark and rough surfaces are better radiators of heat than smooth and polished surfaces; for this reason, stoves of cast-iron are better warmers than those of polished sheet-iron. So, for a like reason, vessels, as tea and coffee pots, for retaining the heat of the liquids they contain, will do this much better if made of smooth and polished metals.

The rays of heat incident on a concave reflector may be converged to a focus the same as light.—This may be shown by an arrangement seen in Fig. 263, where *a* and *b* are two brightly polished copper reflectors, of the parabolic form, placed exactly opposite each other, and in the same line, at a distance of from ten to twenty feet. Let these stand in a dark room, and in the focus of *a* place a ball of cast-iron, heated a little below redness. The rays of heat radiated from this upon *a* will be reflected and fall on *b*, by which they will be converged

Fig. 263.



What laws does radiant heat follow? Do all surfaces radiate heat with the same facility? What surfaces do this with the greatest facility? What is said of liquids heated in brightly polished vessels? What is said of the reflection of heat? Explain this by Fig. 263. How may certain combustibles be ignited without any visible cause?

to a focus. The bulb of a thermometer placed in this focus will show a powerful heat; and tinder, phosphorus, and gunpowder, placed in the same position, will be inflamed without any visible cause, since no light appears.

325. *Transmission of Heat.*—Heat and light, as we have already remarked, are independent agents, although governed in most respects by similar laws. In the facility with which they traverse various substances, the rays of heat and light differ widely. Many substances which are transparent to light intercept the passage of heat, while many which intercept the light transmit heat freely. Thus, if a piece of plate-glass, which allows of the ready transmission of light, be placed before a fire, it will intercept the rays of heat, and become soon heated, while a crystal of rock-salt, of equal thickness, placed at the same distance from the fire, becomes scarcely warmed. Such bodies as plate-glass, which allow the passage of light, are said to be *diaphanous*, while those, as rock-salt crystals, which transmit heat freely through them, are termed *diathermous.*

326. *Cold and its Causes.* — Cold is simply a negative term, and implies the absence of heat. This is produced whenever bodies change from a denser to a rarer state. In such a case the capacity of the body for holding heat is said to be increased, so that the quantity of this sufficient to be rendered sensible in the denser state is absorbed and disappears or becomes *latent* when the body assumes a rarer state. This heat, which is absorbed, or becomes latent, is again given out and rendered sensible, when the body is once more compressed and made to occupy its former limits.

This capacity of bodies for heat may be illustrated by a

In what do the rays of heat and light differ widely? Illustrate this by pieces of plate-glass and rock-salt crystal placed before a fire. What term is given to substances which allow the light to pass through them readily? What to those that allow heat to pass through them? What is cold? When produced? Why is cold produced when bodies pass from a denser to a rarer state?

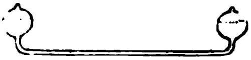
sponge containing water. If the sponge be compressed, the water will flow out and become perceptible, but upon removing the pressure and allowing it to expand, its capacity for holding water will be increased so as to absorb this and appear comparatively dry; upon again compressing it, the latent water contained in it will be forced out and again rendered perceptible.

327. *Cold produced by Evaporation.*—The capacity of liquids for holding heat is greatly increased when they are made to assume a state of vapor, and hence it is that evaporation is a cooling process. Thus, a bowl of any hot liquid placed where the evaporation may go on freely, soon becomes cooled, owing to the escaping vapor carrying away from the liquid its heat.

Thus it is that sprinkling the floor in a warm and dry day renders it cool, since the increased capacity of the vapor for heat takes it from the floor. From the same cause damp clothes, owing to the vapor escaping from them, rapidly take the heat from the body, and reduce its temperature. Hence the danger from taking cold by wearing such.

This may be illustrated by the *Pulse-glass*, Fig. 264, which consists of two bulbs blown upon the extremities of a glass tube, and containing some colored water or alcohol; from the space above the liquid the air has been expelled by heat, and the glass then sealed so as to leave a vacuum within. If one of the bulbs be grasped by the hand, the warmth of this will cause evaporation to proceed rapidly from the liquid in the other bulb, which will absorb the heat from that in the hand, and produce a sensation of cold quite perceptible.

Fig. 264.

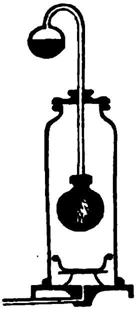


The cold produced by evaporation may be illustrated by an

How may the capacity of bodies for holding heat be illustrated? How does evaporation produce cold? Why does sprinkling the floor in a warm day cool it? What is the Pulse-glass? How is the cold produced by this occasioned?

arrangement seen in Fig. 265. A glass tube, with a bulb upon each end, and bent as seen in the figure, is inserted in an air-tight brass cup, covering the top of a receiver, resting on the plate of an air-pump. These bulbs contain a small quantity of pure water, which, when placed for an experiment, should be allowed to flow into that upon the bent extremity of the tube. The other bulb within the receiver has a covering of cotton placed around it.

Fig. 265.



Experiment.—Dip the cotton in some sulphuric ether, and with a small cup placed over the hole of the air-pump, to prevent the liquid ether entering this, place the cup, with its glass, tightly upon the receiver, well fitted to the pump-plate. Exhaust, and the vacuum formed will hasten the evaporation of the ether * from the cotton, and the cold thus formed will condense the vapor of the water within the lower bulb; this will produce a vacuum over the water in the upper bulb, causing this to evaporate with such rapidity as to freeze in four or five minutes. A person may be well-nigh frozen in a warm day by winding about the body a sheet dipped in ether.

The same results may be produced by plunging the lower bulb in a freezing mixture of salt and snow. This instrument was invented by Dr. Wollaston, and named by him the *Cryophorus*, or frost-bearer.

328. *Water Frozen by its own Evaporation.*—A most remarkable instance of intense cold, produced by evaporation, is shown by the following celebrated experiment first performed by Leslie.

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* With an air-pump, designed for nice experiments, this with ether should never be performed, since the vapor of the ether acts on the valves, and seriously injures them.

Explain Fig. 265. Give the experiment with this apparatus.

Experiment. — Place upon the plate of the air-pump, Fig. 266, a broad and shallow basin of sulphuric acid. Over, and just above this, upon a wire-stand, place a shallow metallic cup filled with pure water. Cover all with a glass receiver well fitted to the pump-plate, as seen in the figure. Exhaust, and produce a vacuum in the receiver; vapor will now escape rapidly from the surface of the water, and be absorbed by the sulphuric acid; this will take the heat from the water with such rapidity as to freeze it in from thirty to sixty seconds.

Fig. 266.

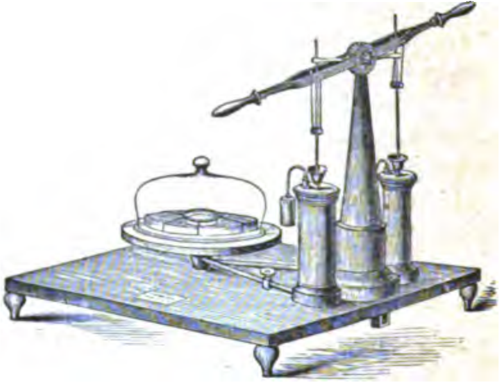

Fig. 267.

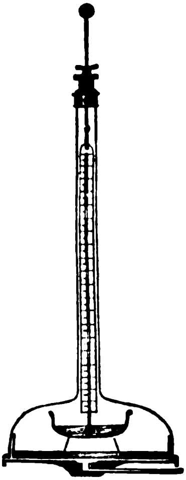

Fig. 267 is a convenient apparatus for showing, by means of a thermometer, the sudden change in the temperature of the water during the progress of evaporation in a vacuum, as just described. The bulb of a thermometer, suspended by a sliding-rod in the long neck of the receiver, may be

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Give the experiment for showing the manner in which water may be frozen by its own evaporation in a vacuum. For what is the apparatus seen in Fig. 267 designed?

lowered into the water in the cup over the basin of acid, as seen in the figure.*

Freezing Mixtures.—Whenever a solid is rapidly converted into a liquid, intense cold is produced. This may be shown by mixing together salt and snow, or pulverized ice, which mutually dissolve each other, and take the heat from the surrounding objects. In this manner creams are frozen during the warm days of summer.

By mixing together three parts of chloride of lime and two of snow, a cold of 50° below 0° may be produced, and mercury thereby frozen. The greatest artificial cold yet produced (175° below 0°) is from the rapid evaporation of solidified carbonic acid gas in a vacuum.

* This experiment is one of the most rigid tests of the air-pump now adopted. If a pump will freeze a small cup of water in from one-half to three minutes, without the aid of ether or other evaporating liquids, its operation may be deemed satisfactory for all the varieties of pneumatic experiments. An air-pump in possession of the author has repeatedly performed this experiment in less than one minute.

How may freezing mixtures be prepared? Cause of the cold produced by these? What is said of the cold produced by a mixture of chloride of lime and snow? By what means has the most intense cold yet known been produced?

ADDITIONAL PHILOSOPHICAL INSTRUMENTS.

329. *The Magic Lantern.*—This is an interesting form of the single microscope adapted for exhibiting, on an extended scale, pictures painted on glass, and natural objects more or less transparent to light. The object, in this case, is highly illuminated by an artificial light, and its image, greatly magnified, is thrown on a screen more or less distant from the lens. Thus this *image* is viewed by the eye, instead of the object itself, as in the common form of the simple microscope.

The Magic Lantern, in the early periods of its use, like most other philosophical machines, was employed as a mere toy for amusing children. The earlier forms of this instrument were exceedingly rude and imperfect, consisting simply of a hemispherical condensing lens fixed in a side tube, and a magnifier placed in a second tube sliding in the first, which extended from the side of a tin canister, while *before* both of these lenses was placed the picture to be magnified. With such an apparatus but little dignity or interest attached to these early "shows." As improvements were, however, subsequently made in the construction of this instrument, it came to be employed for exhibitions of greater utility and interest, until it may now be regarded as well-nigh indispensable to popular lecturing.*

The convenient and attractive form of exhibitions with the Magic Lantern has caused this instrument to be extensively employed by teachers and lecturers on popular science. We shall, therefore, devote a brief space to directions in regard to its uses and liabilities, under the various forms in which it is employed for popular exhibitions.

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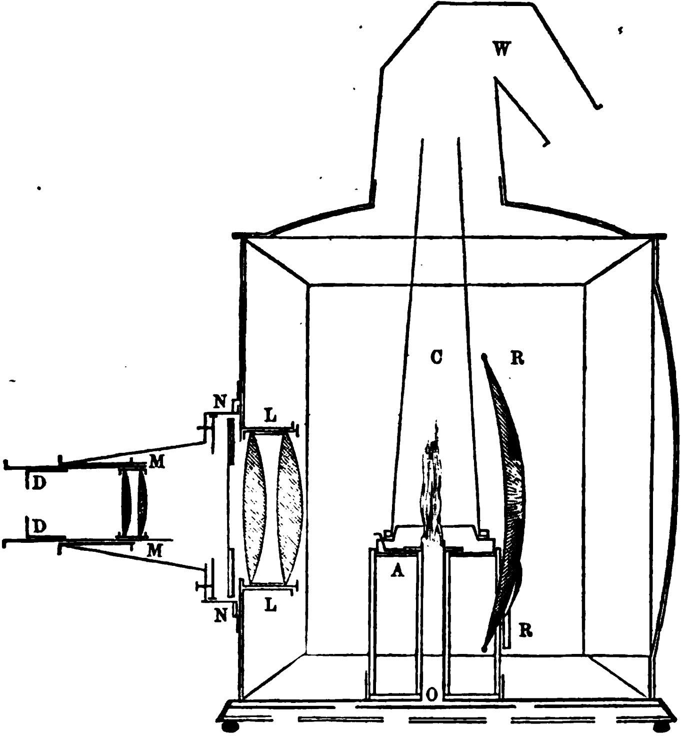
* No lecturer has done more than Dr. Lardner to dignify the Magic Lantern, and show its real utility for scientific and other illustrations. The striking views with this instrument will be remembered by those who listened to the instructive lectures delivered by this distinguished philosopher, a few years since, in this and other cities of our country; contrasting as they did with the too many mere tawdry shows with this instrument, given by those who have neither science nor the requisite mechanical skill.

Fig. 268 presents a sectional view of the internal structure of the Magic Lantern. A is an argand lamp, which is placed

Fig. 268.



in a tin box or case, and may be fixed in its proper position; this lamp is supplied with air through a circular opening in the bottom of the lantern, at O. C is a conical glass chimney, for giving steadiness to the flame, and for conducting the heated gas out through the opening, W, which is bent so as to prevent the escape through it of the inclosed light.

R R is a metallic *reflector* * for throwing the light radiating towards it back upon the large convex lenses, L L. These lenses, known as *condensers*, are fixed in a short tube within the lantern, and serve to condense the light falling on them on the object painted upon the sliders; these sliders move through a narrow slit, N N, at the head of the larger external tube, and are held in their proper positions by springs.

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* In this position of the reflector, the lamp standing within its focal point has its light reflected *diverging* upon the condensers; by this ar-

The light from the illuminated object falls on the *magnifying* lenses, M M (§ 286); by these an enlarged image is formed on a screen before the lantern. D D is a movable *diaphragm*, with a circular aperture, for the purpose of cutting off such scattering rays as tend to injure the distinctness of the picture. The magnifying lenses are fixed in a smaller tube sliding in the larger, which may be moved nearer or farther from the object to suit the focal distance. The whole internal surface of the lantern and tubes is painted black, to prevent any reflection of the irregular light.

330. *Directions for the use of the Magic Lantern.*—The lamp should be well trimmed before using, and filled with the best sperm or lard oil; the wick being even and raised as high as may be without smoking.

The reflector, glass chimney, and lenses, should all be removed before an exhibition, and carefully wiped; with the lenses a piece of clean buff-leather or silk handkerchief may be used, and a circular movement given in wiping. Avoid getting finger-marks on these, and see that they are replaced in their proper positions, as shown by the cut.

The lantern should be placed on an elevated stand (See Fig. 271), at distances from the screen varying from eight to twenty-five feet, according to the focus of the magnifier, the degree of

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rangement a greater quantity of light is made to fall on the condensing lenses than by the former method, where the reflector was fixed upon the rear surface of the lantern, so as to *converge the less amount* of light falling upon it on the lenses. These reflectors should be made of a parabolic form (§ 273). Much depends on their proper form and position.

the illumination, and the size of the circle which it is desired to form on the screen. At the splendid exhibitions with the Oxhydrogen Microscope, given by Mr. Whipple at the Tremont Temple, in this city, in 1850, the lantern was placed at a distance of sixty feet from the screen. The author of this work has recently assisted in arranging an extensive apparatus for exhibiting the dissolving views, where the lanterns were placed about forty feet from the screen. About ten feet is the usual distance. As the same amount of light is thrown on a small as on a large circle, the brilliancy of the picture formed on the screen will, of course, diminish as its magnitude is increased. With the illumination from an oil lamp, a circle of eight or ten feet diameter is sufficiently large. With the Drummond Light, one of fifteen or even twenty feet may be formed.

The position of the lamp in the lantern should be such as, when lighted, to cast upon the screen *a well defined and uniform circle of light.** In some lanterns this position of the lamp is fixed; in others it is determined by an adjusting-screw upon the outside, which moves it to and from the condensing lens, as may be required.

The sliders are placed in the slit with their pictures *inverted.* These should be free from dust, and arranged in a box, so that they may be readily taken up in the order in which it is desired to use them. The magnifying lens may be adjusted to its focal distance from the painting by means of the sliding-tube in which it is fixed. During the exhibition no light should be allowed to escape into the room, except that passing through the lenses upon the screen.

The position of the lamp and lenses should be carefully adjusted before the lecture, and the lantern allowed to stand for some time previous in a warm room, so that the lenses may become warmed, and thus prevent the moisture condensing on them, and so injuring their transparency, as is often the case in cold weather.

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* See that the lenses of the inner and outer tubes are in a direct line.

331. The *Screen* on which the picture is thrown should be white. A plastered wall, hard finished, or piece of cloth twelve or fifteen feet square, well covered with white paint, and attached to a roll, forms a suitable screen. Where the screen is interposed between the spectators and the operator, as in producing the phantasmagoria, it should be rendered as *transparent* as possible. Such may be made by smearing over bleached cotton, or linen, with a coat of white wax, or by using muslin or bleached linen stretched on a vertical frame. Wetting occasionally with water during the exhibition, improves the transparency of the two last; this may be done by a small syringe.

Since nearly half the light is intercepted and prevented from passing through such screens, the picture formed on them is, of course, much less brilliant than those formed on opaque screens prepared as already described. These transparent screens, however, possess the advantage of allowing the operator and lantern to be concealed from view, causing the picture to appear suspended in the air, and so rendering the illusion more perfect.

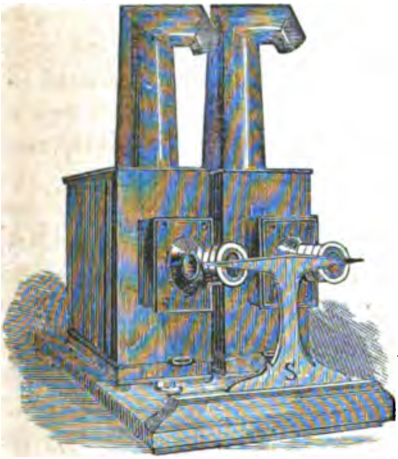
332. *The Phantasmagoria.* — This singular illusion is produced by the formation of an image on a transparent screen, as we have just intimated. In this case the operator is concealed from view, and as the screen is not seen, the images formed on it appear suspended in the air.

Let the operator, standing quite near the screen, and holding the lantern under his left arm, with his right hand adjust the focal distance of the lens so as to form a distinct picture on the screen; then moving slowly from this, and at the same time regulating the focus of the lens, the picture will gradually increase in magnitude, and appear as if approaching the spectators; upon returning again towards the screen, the picture will appear to recede. If the lenses and quantity of light be properly regulated the illusion will be complete, and the effect most wonderful.

333. *Dissolving Views.* — These are most extraordinary magical effects, produced by placing two lanterns of equal power so as

to throw two pictures of equal magnitude, and in the same position, on the same space of the screen. The lanterns are placed side by side on a stand, as shown in Fig. 269, and may be adjusted to the proper angle with each other by turning on pivots in front, and, when so adjusted, made permanent by binding-screws. A diamond-shaped shade, S, slides in a groove in front of the lanterns, and is so proportioned that its widest part, when directly before one of the nozzles, shall wholly intercept the light through that, while its point just reaches to the outer edge of the other nozzle. Thus, in moving this sliding-shade, the light from one lantern is cut off from the screen just in proportion as that from the other is let on.*

Fig. 269.



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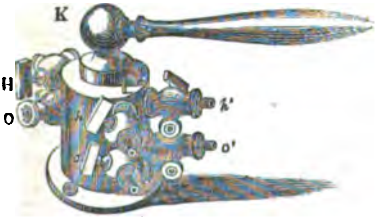
* *Dissolving Stop-Cock.*—In the recent arrangement of these dissolving lanterns, where the Drummond Light (see § 334) is used for illuminating, instead of the slide S, a Dissolving Stop-Cock, Fig. 270, is employed, for alternately letting on and closing off the light.

Fig. 270.



The cylinder of this is fixed upon the rear part of the stand, between the lanterns. The tube from the oxygen bag is screwed to the stop-cock, O, that from the hydrogen bag or generator, to H. From the stop-cocks, *o o'*, lead small rubber tubes for conveying the oxygen to the compound blowpipes arranged

With the lanterns and lights properly adjusted, let two sliders be placed in the slits, one for instance representing a landscape by day, and the other precisely the same landscape by night; and let the light through the nozzle which contains the landscape by day be unobstructed, while that through the other is intercepted; the picture on the screen will then represent the landscape by day. If the shade be now slowly moved, the nozzle of the lantern which shows the day-landscape will begin gradually to close, while that which shows the night-landscape will gradually open. The effect will be that the daylight will gradually decline upon the picture, and the objects represented will assume by slow degrees the appearance of approaching night. The gradual change will go on until the nozzle of the

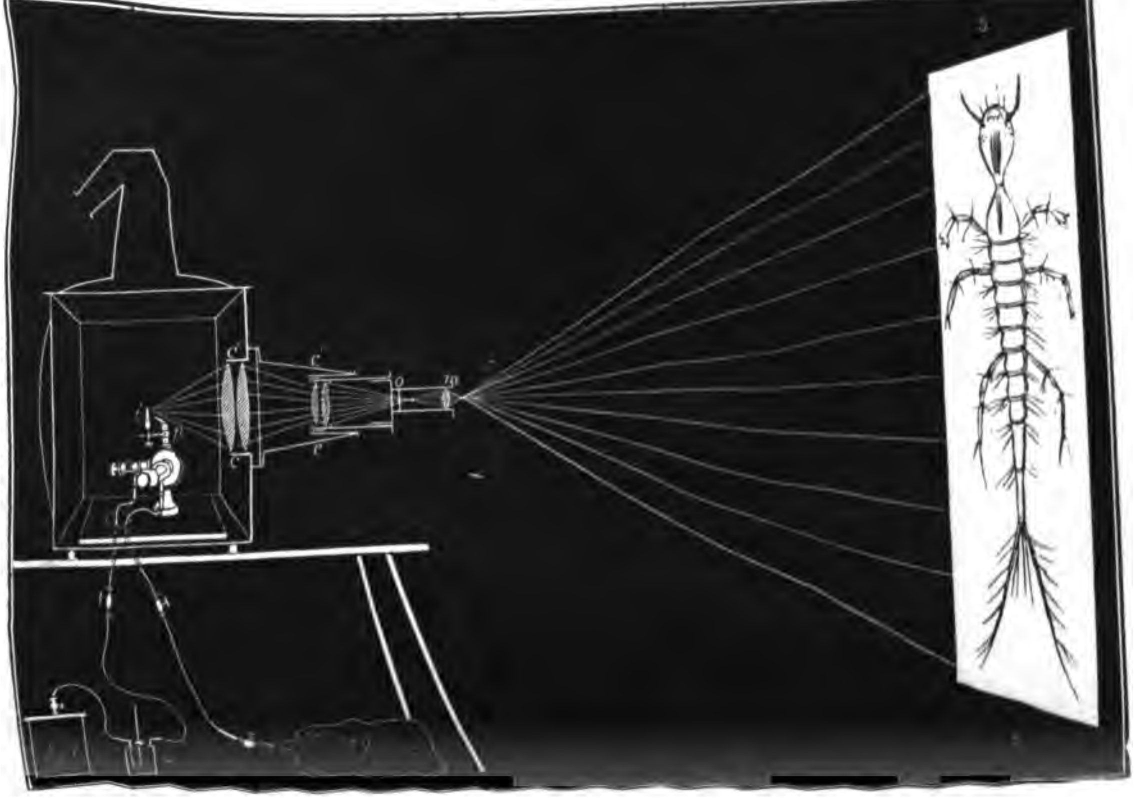
in either lantern, as seen in Fig. 271; from *h h* lead the hydrogen tubes for conveying hydrogen to these same blowpipes. K is a key, nicely fitted, to turn in the cylinder; through this key, opposite O and H, are two holes, which connect, one with the stop-cocks *o o'*, the other with *h h'*, and in such a manner that when the lever of the key is turned towards the side *h o*, the blowpipe of the lantern connecting with these will be fully supplied with the requisite proportion of gases from O and H, while these gases will be cut off from *h' o'*; and so, when the lever is turned in the opposite direction, the gases flow through *h' o'*, but are cut off from h o.

Thus the Drummond Light is gradually produced in one lantern, while at the same time it is as gradually closed off in the other, and so causing a most wonderful dissolving effect. To prevent the jet of gas from being wholly extinguished, so as to require re-lighting at each turn of the key, two fine slits are made on this upon each side of the hydrogen hole, whereby this gas, which is the combustible gas, may be allowed to flow, in a minute quantity, through the jet from which the oxygen is cut off, and so support the flame. To regulate the distance to which the key may be turned without extinguishing the hydrogen jet, a small pin is fixed in the side of this key, which strikes against two others set at the proper points on the upper end of the cylinder.

The stop-cocks, O H, may be left entirely open, and the requisite amount of gases for each be regulated by the stop-cocks upon the opposite side of the cylinder.

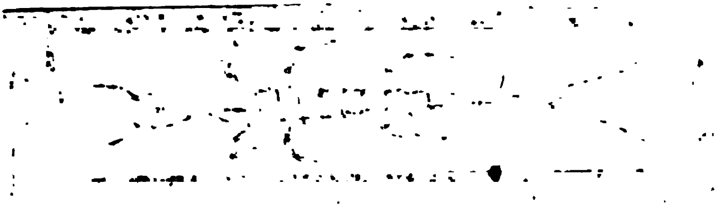
For illuminations with the Drummond Light, no arrangement now in use equals this in point of economy and convenience. For the preparation of the gases and regulation of this light, see a future section. Near the stop-cocks, O H, the cylinder is stamped with these initials, for indicating to which the oxygen and hydrogen tubes should be attached.

Plate 271



[illegible] is completely [illegible]
[illegible] when the
[illegible]
[illegible]

[illegible]



lantern containing the day-picture is completely closed, and that containing the night-picture completely open, when the change from day to night will have been completed.* So other scenes may be made to *dissolve* imperceptibly one into the other.†

334. *The Oxhydrogen Microscope.* — This, in principle, is similar to the Magic Lantern, and is used in connection with that instrument; the object being intensely illuminated by the rays from the *Drummond* Light,‡ concentrated upon it by the lenses of the lantern, and then magnified by a powerful magnifier, so as to form on a screen an image of huge proportional dimensions.

Fig. 271 shows a proper arrangement of this apparatus. A small cylinder, *i*, of quicklime, is placed in a movable socket, and so adjusted that an ignited jet of oxygen and hydrogen gases shall blow through the compound blowpipe, *p*, against its upper extremity, on the side next the lenses. This produces an intense light, which, falling on the condensing lenses, *c c*, and then on those at *c′ c′*, is converged by these last on the minute object at *o*, situated just without the focus of the magnifying lens, *m*. This object, thus powerfully illuminated, is then magnified by *m*, and its image thrown upon a white screen, as shown at S S.

The gases supplying the jet pass from the oxygen bag and hydrogen generator, placed beneath the stand, up through the small rubber tubes, meeting and commingling just as they escape from the extremity of the compound blowpipe, *p*, where they are ignited.*

---

* Lardner.

† The pictures should be of the same size, and placed exactly in the centre of the lenses.

‡ The Drummond Light, so called from its discoverer, is formed by the incandescence of a small cylinder of quicklime placed in the jet of the oxhydrogen blowpipe. This is one of the most brilliant artificial lights known. The lime cylinders used with this light, except when in use, should be kept free from air in a small bottle provided with a tallowed cork; in this way, when purified hydrogen is used, the same cylinder may be made to afford a light through two or three exhibitions. During the exhibition the cylinder should be occasionally turned in the tube, so as to present a fresh surface to the jet.

These rubber tubes enter the lantern through a circular opening at the bottom, and a corresponding opening in the wood stand on which is fixed the blowpipe arrangement. The tubes conducting the gases from the oxygen bag and hydrogen generator connect with the body of the blowpipe by means of two gallows-connectors (Fig. 58); that conveying the oxygen should connect with the *inner* or central tube of the compound pipe, *p*. To prevent the possibility of a mistake, the screw-holes for the gallows-connectors have marked beside them, H, O, corresponding with the hydrogen and oxygen tubes. The quantity of the flow of these gases may be regulated by the two small stop-cocks in the tubes beneath the lantern.†

The luminous point of the lime should be directly in a line with the centre of the lens, and near its focus. If this point deviate only a trifle from the exact point required, the circle of light on the screen will be defective; this position may be obtained by means of regulating-screws in the wood-stand.

The directions in regard to the lenses, the distance from the screen, and the luminous circle described on this, are the same as for the magic lantern. The objects, such as portions of flies' legs and wings, cheese and fig mites, bees' stings, portions of

---

Fig. 272.

* This blowpipe is formed from two small copper tubes, one within the other, connecting at their lower extremities with the two rubber hose. Thus, the gases (which, when mixed, form an explosive compound) do not mingle until just as they escape from the ends of the concentric blowpipe. By this form of the jet all possibility of an explosion is removed. Fig. 272 shows an arrangement of the concentric tubes of this compound blowpipe, where the openings are shown of the usual size.

† In the arrangement of the oxhydrogen microscopes now made by Mr. Chamberlain, of this city, the gallows-connectors are dispensed with, and in their place are two small stop-cocks connecting the rubber tubes directly with the body of the jet. This dispenses with the small stop-cocks beneath the lantern, and so facilitates the regulation of the flow of the gases of the jet.

hairs, animalculæ in water,* etc., are fixed in circular apertures, on strips of thin plate-glass, or confined in cavities between this, as shown in Fig. 252.

The oxhydrogen microscope is peculiarly well adapted for popular evening exhibitions, since the images of minute living objects may be formed on a screen, before the audience, of surprising magnitudes. Thus, while the common form of microscope allows of the objects being viewed by only a single eye at a time, the oxhydrogen presents the same at once to a whole assembly.

The size of the image varies with the distance of the magnifier from the screen, and this distance may be increased in proportion as the illumination is more intense. Thus, minute objects may be magnified in surface *many millions* of times, so that the image of a flea or a louse shall appear in magnitude equal to an ox or elephant, and the animalculæ of a drop of water like huge monsters swimming in a deep ocean.

The preparation and use of the gases for forming the Drummond Light.—This light, as already intimated, is formed by the incandescence of lime produced by an ignited jet of oxygen and hydrogen gases, mingled in certain definite proportions; these proportions being about two parts, by volume, of hydrogen to one of oxygen, as in the formation of water, of which they are the elements.

Oxygen gas, besides being the chief element of water, is also the vital principle in common air, and enters very largely into the composition of various earths and salts. This gas supports combustion, causing bodies to burn in it with surprising energy, but does not itself burn. It may be prepared from a great variety of substances, and in a variety of ways, through the agency of heat or acids. We shall, however, describe only two methods, which, in our judgment, combine in the highest degree convenience and economy.

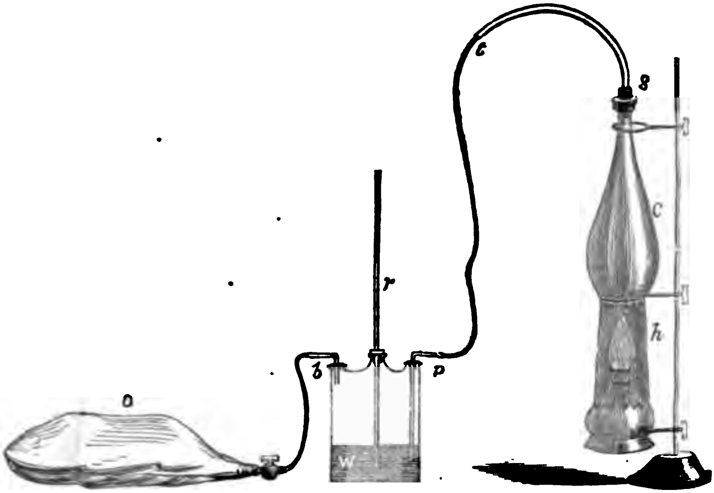
---

* Ordinary well-water, or water that has been subjected to considerable pressure, contains few if any animalculæ. These are best shown by water from a pool exposed to sunlight.

The first and preferable method of making oxygen is from *chlorate of potash*, a salt largely composed of this gas, and which yields it in great abundance and purity when heated.

Fig. 273 exhibits a convenient apparatus for preparing oxygen for the Drummond Light, or other purposes. C is a copper flask, varying in capacity from one pint to a quart, provided with a plug, *s*, which screws into its nozzle against an *air-tight* shoulder; to *s* is attached, by soldering, a brass tube; over the end of this tube, at *t*, a proper distance from the heated flask, is slipped an elastic rubber hose; the other extremity of this hose is also slipped upon the end of a glass tube, *p*, bent at a right angle, and extending down about an inch below the surface of the water, w, in the Woulf's bottle or purifier. *r* is a safety-tube of glass, also passing down through a tightly-fitting cork into the water. From the outer end of a second bent *glass* tube, *b*, leads another hose, connecting with the stop-cock of the large rubber bag, *o*. Beneath the copper flask is a sheet-iron chimney, *h*, which serves to conduct the flame from a spirit-lamp, on which it stands against the bottom.

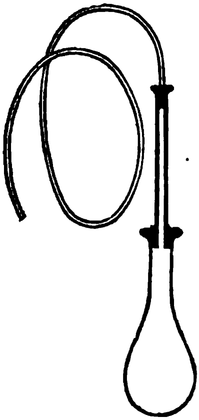
Fig. 273.



Directions for making Oxygen. — Expel the air as far as possible from the rubber bag by rolling it up compactly, and then close the stop-cock attached to its nozzle; remove the screw-plug, s, and pour into the copper flask from five to eight ounces of chlorate of potash,* well mixed with two or three of powdered oxide of manganese; see that the screw and face of the neck are free from any dust, and then replace the plug. Connect the hose leading from *t* with the purifier, and also that from the rubber bag with the same, at *b*; place a spirit-lamp † beneath the flask, as shown in the figure, and, with the stop-cock open, let there be a free communication through the water of the purifier into the bag.

In five or ten minutes the potash will melt, and form with the manganese a semi-fluid compound, when a decomposition of the former will soon commence, and the gas pass over with a free and uniform flow, being cooled and purified in its passage through the water. When the bag is filled, or the gas ceases to pass over, remove the lamp, slip the hose from *t*,‡ and close the stop-cock. The gas is now ready for use, and, when wanted for the Drummond Light, may be attached, as in Fig. 271. If judiciously used, twelve or fifteen gallons of oxygen will supply a single light from one to one and a half hours.

Fig. 274.



A second method of preparing Oxygen Gas, is by heating powdered per-oxide of manganese in a cast-iron bottle, Fig. 274. This bottle is of the same capacity of the copper flask, and has a tube, ground to fit tightly its neck; from this tube leads a hose connecting with the purifier. Fill the bottle about half full of manganese, and place in a coal fire. At a red heat the manganese will part freely with its oxygen, which will flow over as from the chlorate potash just described, but in less purity than from that salt.

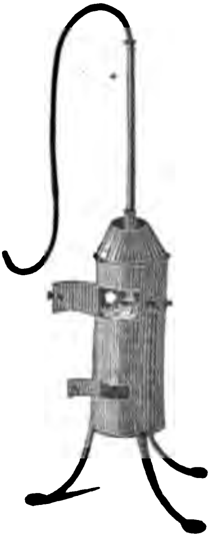
---

* Every ounce of this salt will yield about one and a half gallons of oxygen. This, however, depends on the purity of the potash, which should be kept in close jars, and free from the moisture of the atmosphere. Good chlorate of potash usually has a thin scaly appearance, and a shiny lustre.

† These alcohol lamps are provided with a ground-glass cap, fitting tightly over the wick. When the lamp is not in use this cap should be kept on.

‡ Guard against removing the lamp and allowing the flask to cool while connected with the bottle; for, in such case, the vacuum formed in the flask will cause the water to flow over into this. After using, pour into this copper

Fig. 275.



335. Fig. 275 shows a small portable stove, convenient for holding the bottle in the manufacture of oxygen. With this bottle oxygen may be also made from chlorate of potash, requiring, however, the heat of a coal fire.

The *hydrogen* for the Drummond Light may be used directly from the generator, or after passing through the purifier,* as seen in Fig. 271. Occasionally, however, it is convenient to prepare the gas previously, and use from a second bag like that for the oxygen in that figure.†

---

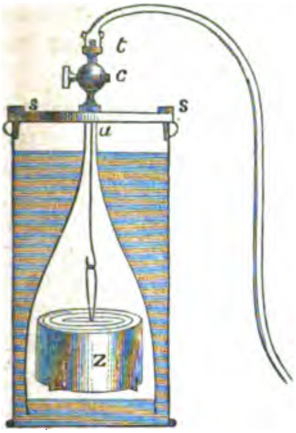
flask, while hot, two or three gills of water; this will dissolve the manganese, etc., which has become hard, and allow it to be poured out; in this way the flask may be easily cleansed; if allowed to stand a while and cool, the process of cleansing becomes difficult. Guard against piercing the soft copper by sharp sticks, wires, etc.

* This, as well as oxygen, carries over with it certain volatile acids and other impurities, which are stopped and received by the water.

† The gas, when burned from the compound blowpipe, should be forced from the bags by a moderate pressure. For obtaining this pressure a wide board may be used, with one end resting on the floor, and sustaining a weight of forty or fifty pounds. This bag may be placed in a box beneath the stand, and a pressure better applied, if desired. Guard against getting this in any way pierced. Experience will alone teach the necessity of proper care in all experiments with these gases; mere written or verbal cautions seldom impress the careless operator sufficiently to insure proper care.

The *Hydrogen Generator*, Fig. 276, is a convenient apparatus for the rapid manufacture of this gas. This consists of a cylindrical copper cistern, holding from two to seven gallons, provided with a wood cover, held firmly to the cistern by the binding screws, *s s*, and having a stop-cock, *c*, extending down through its centre, to the lower extremity of which, at *a*, screws a copper bell.* Within this bell is suspended a copper bucket filled with granulated zinc, or, which is preferable, a roll of sheet zinc, Z, resting on cross-wires, hooked to a main wire fastened to the cap of the bell. A rubber hose, *t*, is attached to the upper end of the stop-cock *c*, and leads off to the purifier or other vessel, as seen in Fig. 277.

Fig. 276.



336. *To prepare the Hydrogen Generator.*—Fill the cistern nearly half full of water, into which pour about one-fifteenth its bulk of sulphuric acid, and mix well; lower the bell with its zinc into the liquid, and secure the cover by the binding-screws; open the stop-cock, and allow the liquid to rise in the bell, and then close it again. The action of the acidulated water on the zinc will evolve hydrogen rapidly, and expel the liquid from the bell; † as soon as this is forced below the zinc, as shown in Fig. 276, the action will cease. The stop-cock may now be

---

* A leather-washer should be placed on the cap of this bell, between this and the wood, to avoid the possibility of a leakage.

† The rationale of this is as follows: The water is decomposed; its oxygen uniting with the zinc forms an oxide of zinc, while the hydrogen, the other element of the water, is set free. The office of the sulphuric acid is to dissolve the oxide of the metal as soon as produced, and form with it a salt (sulphate of zinc), thus inducing a decomposition of the water.

opened, and the gas allowed to blow off; this should be done *twice*, so as to allow the bell to be freed from any mixture of atmospheric air before a flame is applied; otherwise an explosion, caused by the impurity of the hydrogen, may result upon the first application of a flame to the jet.

The generator, thus prepared, may be kept for use at several exhibitions, or until the action of the liquid has become too feeble, owing to the union of the acid with the dissolved metal, to form a sulphate of zinc, when a fresh mixture should be substituted. If the hydrogen is to be received in a bag, after passing the purifier, as seen in Fig. 273, this bag should be freed from air, and attached as in the case of oxygen already described.

To regulate the flame of the oxhydrogen jet, Fig. 271. —With the stop-cocks attached to the bag and generator entirely open, turn the small stop-cock of the tube connecting with the latter, and allow nearly a full flow of hydrogen; ignite this with a taper, and then let on, through the other small stop-cock, oxygen, until the jet is reduced to a small bluish-white flame; such a flame causes intense heat, which will soon cause the lime to become of a most brilliant white A very good light may be obtained by substituting for the hydrogen bi-carburetted hydrogen (street gas), or even by allowing only a jet of oxygen to blow through the flame of a lamp, upon a piece of lime properly arranged.

The Solar Microscope.—This is similar in its operation to the oxhydrogen microscope just described. For illuminating the object in this, solar light is employed. The tube containing the lenses is fixed in an opening of a window-shutter, and a mirror is placed upon the outside in such a position as to reflect the sun's light upon the condensing lens. No artificial light can equal this for illumination; but, as the solar microscope can be used only by day, and when the sky is unclouded, it is less serviceable for popular exhibitions than the oxhydrogen microscope, which is best used at evening.

The Benzole Light.—An interesting application of hydrogen has, within a few years, been made to the production of the celebrated Benzole or Water Light. By means of a variety of ingeniously-contrived machines, this light, which considerably exceeds in brilliancy the common gas light, has been applied to purposes of illumination, and many large factories, and public as well as private dwellings, are now lighted from this source.

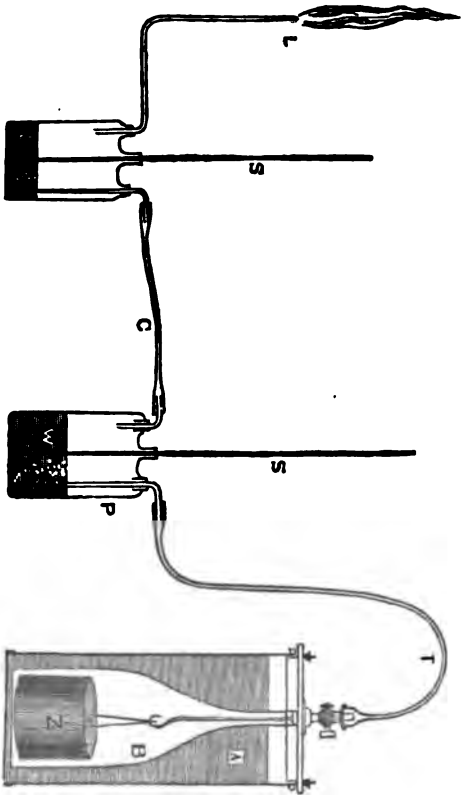


Fig. 277.

Fig. 277 presents a simple apparatus for exhibiting this light in the lecture-room, or for individual amusement. A, B, and Z, represent the acidulated water, the copper bell, and roll or bucket of zinc, of the hydrogen generator, as already described. From the stop-cock of this leads the rubber hose, T, for conveying the hydrogen gas to the water of the purifier, P; this hose is slipped upon the end of the right-angular glass tube, which enters the water, W, after which, it is conveyed through the second rubber hose, C, down into a small quantity of *benzole* contained in the second bottle, at D. From this the hydrogen receives a due proportion of carbon, the luminous principle of flame, and the compound gas thus formed (carburetted hydrogen) escapes through a small jet at L, where it is burned, as shown in the figure. S, S, are safety-tubes, up which the liquids may rise whenever there is an undue pressure. In this way the flow of gas from the jet is made uniform, and any flickering of the flame prevented.

The benzole employed for this light is a volatile oil, resembling naphtha, which contains a very large proportion of carbon, and which it readily yields to the hydrogen when passed through it. Common air, slightly warmed and passed through this oil, will yield a very brilliant light, although inferior to that from pure hydrogen. The glass tube should enter the benzole only about half an inch, lest the hydrogen become too much carbonized, so as to cause the flame to smoke.

The directions for filling the hydrogen generator have been already given. We repeat, that, when filled, the gas formed in the bell should be drawn off at least twice, and the stop-cock, after each time, immediately closed. Any mixture of common air with hydrogen forms an explosive compound. Where the benzole light is employed for illuminating dwellings, a machine is usually placed in the cellar, and the generation of the illuminating vapor regulated by a crank above, which is occasionally turned. With proper skill in using, this benzole light forms both a cheap and brilliant illumination.

The expense of a light procured from the passage of atmospheric air through this liquid is much less than from many of the ordinary methods of illumination out of large cities. The chief obstacle in the way of obtaining light from this source is the readiness with which this hydro-carbon vapor condenses; thus, in cold weather, this becomes condensed in the tubes which pass through rooms which are not properly warmed, so as soon to clog these and prevent the flow of the gases.

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